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An Assessment of Mercury Emissions from Fossil Fueled Power Plants

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An Assessment of Mercury Emissions From Fossil Fueled Power Plants

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16. ABSTRACT

The study has found no evidence of a health or environmental problem as a result of emissions of mercury from power plants. This conclusion has led to the recommendation that a specific control program to address mercury emissions from power plants is not necessary at this time. It is estimated that power plants contributed less than 8 percent of the more than 2000 tons of mercury lost to the environment by all man-made sources in 1974. Studies and scenarios indicate little or no effect of mercury from power plant emissions on ambient air or water concentrations. Localized increases could occur with soil concentrations. Direct relationship of the power plant emissions to ambient concentrations could not be ascertained. Health effects, standards and regulations, transport, and transformations of mercury are discussed.

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SECTION 1

SUMMARY

The uses as well as the harmful effects of mercury have been known to man for centuries. The hazards of mercury have been brought to the forefront, in recent years, by the disaster which occurred in Minamata, Japan, beginning in 1956. Methylmercury, produced in the environment from an inorganic catalyst discharged in the effluent of an acetaldehyde plant, was found to be responsible for the series of poisonings among the villagers. This type of episode was later repeated in Niigata, Japan, in 1964.

The toxicity of mercury depends upon its chemical form, the most toxic being methylmercury. Within the environment and within ecosystems, various forms of mercury can be transformed into methylmercury compounds. This form may concentrate along the food chain, passing on to man through consumption of fish and shellfish. Methylmercury, when ingested by man, is almost entirely absorbed, with its loss from the body occurring at a slow rate.

Mercury poisoning affects mainly the brain and other components of the nervous system, although other organs may also be affected. An acceptable intake (mercury vapor and methylmercury) is considered to be 30 micrograms per day, for a 70 kg person, from air, water, and food. An average diet (water and food) over a long period of time is estimated to contain 10 micrograms per day of mercury. This leaves 20 micrograms per day to be contributed by air.[5] However, an intake of 4 micrograms of methylmercury per kilogram of bodyweight per day would result in mercury intoxication of an adult.[5]

Mercury levels in various animals, fish, and plants in man's food chain are shown in Table 1.[6] In response to the hazard of mercury, the Environmental Protection Agency, Food and Drug Administration, the Department of Health, Education and Welfare (via NIOSH) and the Department of Labor (via OSHA) have promulgated regulations and/or recommendations for ambient workplace concentrations and industrial emissions. These are summarized in Table 4.[8-15]

Mercury is classified as a hazardous air pollutant under Section 112 of the Clean Air Act. In determining the industrial emission standard, shown in Table 4, the health effects were considered together with an adequate safety factor. An ambient air concentration of 1 g/m^3 was found to be compatible with the emission standard in safeguarding health.[5]

Fossil fuel-fired power plants contribute mercury to the environment as a result of the combustion of coal and oil. A total of 968 such power plants generated 1.4×10^{12} KWh net in 1974 from the combustion of approximately 4×10^{8} tons of coal and 5×10^{8} barrels of oil.[19] Based upon a number of studies, the mercury content of an average coal was found to be 2.1×10^{-7} tons Hg/ton coal (0.21 ppm), while an average oil had 31.9×10^{-5} lbs/gallon (0.1 ppm).[21-25,30] Assuming these average values for these fossil fuels, 82 tons of mercury were available to be emitted to the environment from coal and 76 tons from oil in 1974, based upon industry consumption figures. If all of the available mercury from power plants (158 tons) were uniformly deposited over the land area of the 48 contiguous states, to a depth of 2 cm, the mercury concentration in the soil would be 0.34 ppb compared with the average soil concentration of the United States of 71 ppb.[86]

Fossil fuel use by utilities was divided into regions as defined in Table 7. One-third of the total mercury available in coal was in the East North Central states, while 29 percent and 26 percent of that available in oil was in the South Atlantic and Middle Atlantic states respectively. Coal-fired plants emit about 90 percent of this mercury content in the stack gas, with the other 10 percent remaining in the ash to be deposited on land. Oil combustion yields all its mercury to the stack gas.[30-33]

Total mercury losses from utilities, however, appear to represent less than 8 percent of the more than 2000 tons lost to the environment by all man-made sources in 1974. The mercury losses were from mining and smelting, unregulated sources, manufacturing and processing, and from the consumption of the products of those industries. These are detailed in Table 8. The mercury consumed by the manufacturing and processing industries in 1974 totaled 2,220 tons. Since U.S. mercury mines produced 83 tons, the difference consisted of reclaimed and imported mercury.

On a regional basis, the largest mercury losses from man-made sources to the environment, 51 percent according to 1973 figures, occurred in the Middle Atlantic, East North Central, and South Atlantic regions. These same areas accounted for 63 percent of the total mercury losses from electric power generation in 1974. The largest losses from natural sources, 53 percent, were in the Mountain states and Pacific states regions. These are also the areas of most mercury deposits and mineralization.

When compared to all man-made sources on a national basis for 1974, utility losses ranked fourth overall, contributing less than 8 percent. Utility losses ranked second for air emissions (24 percent of all losses to air) and ninth in losses to land (0.6 percent of all losses to land). Direct loss of mercury from power plants to water does not occur. Rather, their contribution to water results from the transport of mercury from the other media to water.

Mercury losses to the environment by utilities, and used in ranking, are based on uncontrolled emissions. A review of control technology reveals that

mercury emissions are not directly controlled. However, it is estimated that as much as one-third of these emissions may be controlled if SO_2 scrubbing devices are in use.[32,48] Considering an increase in power generation and the use of SO_2 scrubbers by utilities, it is projected that by 1983, utilities will rank second with 12 percent of the total mercury losses. It is estimated that in 1983 utilities will rank first in air emissions with 230 tons (30 percent of the losses) and seventh in losses to the land with 25 tons (2 percent of the total) for that media. The total losses of mercury by utilities is estimated to be 255 tons in 1983 as compared with 158 tons in 1974. These losses still represent a small part of all mercury losses to the environment.

The mercury hazard depends on both the concentration of mercury and its chemical form in the environment. Methylmercury compounds, as stated previously, are the most toxic. Chemical and biological activity can methylate other forms of mercury thus producing the toxic form. With the addition of physical transformations, the various forms of mercury are transported within the cycle as shown in Figure 2. It is not possible to estimate the amount of mercury and its residence time in the various environmental media within the cycle or along the pathways of transport from current data. A number of studies have indicated the range of ambient concentrations. Normal ambient concentrations in city air have been estimated at 0.0008-0.08 ppb, with concentrations as high as 30 ppb occasionally observed.[30] Rural areas are estimated to have a concentration range of 0.0006-0.008 ppb.[51] The concentration of mercury in industrial workplace air has been reported to be as high as 42 ppb, while air near a geothermal steam vent has been measure at 23.5 ppb.[56]

A worst case condition in the New York City area was considered in determining the effect of mercury emissions from power plants on ambient air concentrations. The scenario considered mercury emissions from the 21 plants in New York City and the immediately adjacent area in New Jersey. The mercury was emitted in stack gas during 1974 and remained, in total, within the 400 square mile area in which it was emitted. These assumptions were made to determine if mercury concentrations could reach hazardous levels under any circumstances. The assumptions were that an entire year's mercury emission from all these power plants was retained in the area at one time, and that no ventilation occurred. The scenario would never occur as emissions would be distributed over the year and meteorological conditions would preclude such stagnation, providing for dispersal and dilution. For an assumed air column of 12 km altitude, the ambient air concentration of mercury from this source alone was found to be 0.65 g/m^3 (0.52 ppb.) This is based upon actual fuel use. The EPA recommended ambient air concentration for 24 hours is ≤ 1.0 g/m^3.[5] The same calculation, assuming all the electricity generated from these plants was only from the combustion of coal rather than the 1974 quantities of both coal and oil, showed a 42 percent lower mercury concentration in air. Therefore, mercury emissions from power plants are not expected to cause an ambient air quality problem. Observed and calculated ambient concentrations, around actual power plants as well as other areas, were orders of magnitude below the standard.

Ambient water concentrations are defined in terms of dissolved mercury, suspended mercury, and mercury in bottom sediments. On both a regional and a national basis the ambient concentrations of all the waterways, whose data were reviewed, averaged well below 2 ppb.[84] This is well within the drinking water standard of 2 ppb, established by EPA as the highest acceptable concentration of mercury allowable for drinking water.[13] These same fresh water bodies may, however, exceed the EPA standard for freshwater aquatic life and wildlife of 0.05 ppb.[9] The detectability limits of the analytical methods used in gathering the data preclude comparison to the standard.

To determine if mercury concentrations in water could reach hazardous levels due to power plant emissions, a scenario similar to that used for the ambient air case was developed for water. In this case, all the emissions to the air were washed out into a river. The ambient water concentraton was calculated to be 0.47 ppb, within the drinking water standard but exceeding the more stringent freshwater aquatic standard. This improbable and excessive case could not occur since complete deposition, whether in water or locally, has never been shown to occur. Distribution of deposited mercury and its dilution would further reduce this concentration by orders of magnitude. These results would be in line with available ambient water quality data.

Existing studies do not indicate a direct relationship between the dissolved mercury concentration in water and mercury emissions from a power plant.[85] Elevated levels have occurred in bottom sediments. While the power plant emissions may have contributed to the condition, it could not be shown to have a direct, quantitative causal effect.

The average concentration of mercury in soils in the United States was found to be 71 ppb, although there are some estimates of 100 ppb or slightly higher.[86] A number of studies have been carried out which have attempted to correlate higher than average soil concentrations with discharges from a particular areas source, generally with inconclusive results.[35,70,85,87-91] In order to determine the effect of mercury emissions from a power plant on land the previous scenario was again considered. When the entire year's mercury emission to the air was deposited on the 400 square mile area considered, the ambient soil concentration, assuming a depth of 2 cm, was calculated to be 145 ppb. This is above the geometric-mean concentration for U.S. soils. The factors of partial deposition, plume dispersion, transport mechanisms, and transformations of mercury would greatly reduce this concentration. A 20 percent assumed deposition alone reduced it to 29 ppb. Actual studies around plants confirm the conclusion that some elevated mercury levels may be found locally, with only partial deposition occurring.[85,91] However, direct relationship to a power plant as a source could not be shown.

SECTION 2

CONCLUSIONS

Several conclusions were drawn, as a result of the available information and scenarios, concerning power plants and mercury emissions to the environment.

- EPA should not develop specific control technology for mercury emissions from power plants at the present time. The bases for this conclusion are: (1) the relatively small contribution of mercury from power plants (158 tons in 1974) when considering all man-made sources (2169 tons in 1974) and all natural sources (1329 tons in 1974); (2) the apparent capability of sulfur dioxide scrubbers to control possibly one-third of the mercury emissions to air; (3) no conclusive evidence of contamination quantitatively attributable to power plants; and (4) the relatively small contribution of mercury projected to be emitted to the environment from power plants in 1983 (255 tons) relative to projected losses from all man-made sources (2131 tons in 1983).

- There is no convincing evidence, from existing data or from our scenarios, that mercury emissions from power plants significantly affect the ambient mercury concentrations in air, water, or land. However, the data are few in number and most cases, of dubious quality.

- Neither the empirical data nor the scenarios indicate a hazard as a result of mercury emissions from power plants. There are no reported incidents known of acute toxicity of mercury from power plant emissions. Incidents of chronic toxicity, associated with power plant emissions, have not been found.

- There is a need to develop better data concerning mercury concentrations, transformations, and transport in the environment, as well as the relationship between ambient concentrations and emissions from various sources.

- The most significant loss of mercury to the environment is from the consumption of manufactured or processed products containing mercury. This loss accounted for 52 percent (1120 tons) of all man-made mercury losses in 1974. It also represented 60 percent (830 tons) of all man-made mercury losses to the land. Recycling could have had an impact on 34 percent (738 tons) of the total man-made mercury emissions, based upon 1974 figures.

SECTION 3

RECOMMENDATIONS

This study has found no evidence of a problem as a result of power plant emissions to the environment. If there had been widespread and excessive concentrations of mercury in the environment and data analysis would have indicated a pattern implicating a specific source, such as power plants, then a control program would have been recommended. Inasmuch as there is presently no obvious problem, no such program is recommended. However, there is doubt as to whether or not available data, upon which this report is based, are correct.

It is recommended that, in view of EPA's limited resources and the findings of this report, a limited program be funded. This program would serve to provide reliable data to substantiate or negate the information used in arriving at conclusions. The following areas of study are recommended:

- Sampling and analysis of soil samples surrounding a power plant, including a characterization of soil type and forms of mercury present.

- Sampling and analysis of plants, especially food crops, and animals in the same area. The key points on which to concentrate are biomagnification, and the forms of mercury present.

Should these data then indicate a problem, then a phased program may be undertaken to further define the problem and develop abatement techniques. Elements of an expanded program, should the need arise, may include the following:

- A complete mercury balance of coal-, oil-, and gas-fired power plants, including the analysis for the different forms of mercury.

- Efficiency of currently used scrubber systems on the control of mercury emissions under varying conditions.

- A sampling and analysis program for determining mercury concentrations in ambient air, water, sediments, soils, and plants. The program should be of a magnitude that will provide the necessary reliable data which may be used to indicate source relationship, define the fate, and characterize the transport mechanisms of mercury in the environment.

- Developing and calibrating a diffusion model for mercury emissions, testing the model on power plant sources.
- Develop criteria for mercury control technology.
- Development and demonstration of control techniques.
- Implementation planning for the selected control technique(s).

SECTION 4

INTRODUCTION

OBJECTIVE

The objective of this study was to determine the need for developing methods for the control of mercury emissions from power plants and other sources and assessing the relationship and significance of the emissions to ambient concentrations.

ORGANIZATION OF THE REPORT

The report includes estimates of mercury emissions, as well as data from scenarios and empirical studies in assessing the significance of mercury emissions from power plants. Conclusions are developed based upon the assessment. The health and ecological effects of mercury are reviewed in Section 5. Several well documented cases of mercury poisoning are described, such as those in Japan and Sweden. In order to understand these types of occurrences, the toxicity of mercury and the symptoms which it produces are described. The amount of mercury which may be tolerated by the body is reviewed in relation to the concentrations of mercury found in the food chain.

The known toxicity of mercury and its occurrence in the environment had led to promulgation of regulations. The standards, regulations, and recommendations are tabulated and discussed. This provides a basis of comparison when assessing the importance of sources emitting mercury.

Fossil fuels are the source of mercury emissions from power plants. The average mercury content of the fuels is presented, as determined from the literature. The consumption of these fuels is tabulated for 1974, on both a national and a regional basis. These data on fossil fuels are the basis for calculating the mercury released by power plants.

In addition to power plants, other sources of mercury are examined. The amount of mercury used by these industries and lost to air, water, and land is estimated. These emissions are then placed in perspective to power plant emissions in terms of relative mercury contributions. The amount of mercury ultimately reaching the environment, when compared with the amount available for release, is dependent upon emission control systems. The present technology of power plant control systems is briefly reviewed as are control technologies of other industries which are sources of mercury.

The significance of power plant emissions can only be assessed when one considers the fate and transport of the mercury and mercury compounds emitted. A model is proposed for the cycle of mercury through the environment, showing the pathways and mechanisms of transport between the media.

To assess the effects of emissions on air, in water, and on land ambient concentrations in each of these media are evaluated The relative effects of mercury emissions from power plants on the ambient concentrations, on a worst case basis, are calculated using scenarios. Documented, empirical studies, relating power plant emissions to ambient concentrations, are reviewed and evaluated in relation to the results of the scenarios.

The report examines the chemical, physical, and biological transformations which occur in each medium. These transformations provide a basis for assessing the problem of mercury in the environment.

Most data used in this report are for the year 1974 because that year's data was the most complete available. In several cases only 1973 data or 1975 data were available. Where possible these data were extrapolated to reflect probable 1974 values.

SECTION 5

BIOLOGICAL EFFECTS AND THE REGULATION OF MERCURY

HEALTH AND ECOLOGICAL EFFECTS

Background

Mercury has been produced and used by man for centuries. Cinnabar (HgS) was used in ancient Egypt and Babylon. The dangers of mercury to humans has also been known for a long time. The early Greeks realized mercury was dangerous when swallowed. The earliest known case of mercury poisoning was in 1579 of a European mine worker. Typical symptoms were identified in the late 18th century. During the past few hundred years one of the industries most responsible for occupational mercury poisoning was the hatter's trade. Mercuric nitrate was used for carroting, or dyeing, of the fur. Frequently whole families that worked in this trade suffered from the disease.[1,2]

Recently, there have been several localized cases of poisoning around the world which have renewed concern about the hazards of mercury to man. One of the most renowned was the Minamata disaster in Japan. The first case of mercury poisoning in this fishing community was discovered in May, 1956 when a six-year old girl was found to be suffering from an unknown cerebral disease. Eight more cases were reported later that month. By November, 1956, the cause of the disease had been identified as a heavy metal contained in fish and shellfish. It was not until 1960 that an organic mercury compound was identified as the cause. In 1962, after an exhaustive study by the Kumamota University, it was concluded that methyl mercury generated from the inorganic mercury catalyst used in acetaldehyde manufacture and discharged in the effluent of a nearby plant, was responsible for the poisoning. The mercury had concentrated in the fish, a main item in the villagers' diet. Since the plant installed mercury control devices, no further outbreaks of mercury poisoning have occurred. The total number of recorded cases of Minamata Disease was 121, of which 22 were congenital. Of the 121 recorded cases, 54 resulted in death.

A second outbreak similar to that in Minamata occurred in Niigata, Japan, during 1964. In this case, 49 persons were afflicted, six of whom died. Once again, an acetaldehyde manufacturing plant using a mercury catalyst was identified as the source of the mercury. In 1969, all industrial facilities manufacturing acetaldehyde and using mercury catalysts were closed.

Sweden first became interested in the mercury problem during the 1950's when a decline in the bird population occurred. This decline was attributed

to methylmercury poisoning from seed grain. Having been alerted by the Minamata disaster, a national conference was called in 1965. It was decided that the major sources of mercury were seed dressings, pulp and paper processing, and chloralkali plants. In 1966, the use of methylmercury compounds as seed dressings was stopped. In 1967, the use of phenylmercury compounds in the pulp and paper industry was banned and measures were enacted to restrain discharge of mercury from chlor-alkali plants.

In 1969, a family in New Mexico was poisoned by eating meat from a hog which had been fed mercury treated seed. In 1970, Idaho found that 25 percent of 300 wild pheasants contained over 1 mg of mercury per kg of body weight and therefore recommended reduced consumption of this fowl.

In 1970 it was discovered that fish from lakes along the United States-Canada border contained large amounts of mercury. Fishing was therefore banned on Lake St. Clair, Lakes Huron, Erie, and Ontario, most of the St. Lawrence River, Hudson Bay, Howe Sound, and Dalhousie Harbor.

Toxicity of Mercury and Symptoms of Mercury Poisoning

Hazards of mercury are related principally to the toxicity of mercury and the localized occurrence of high concentrations in the environment. Unlike other trace metals, mercury is not essential to the life process of any known organism. Toxicity of mercury depends upon the chemical form, the most toxic being methylmercury compounds. In an aquatic ecosystem other forms of mercury can be converted into methylmercury. Methylmercury is concentrated along the food chain and is eventually passed to man through the consumption of fish and shellfish.

In humans, ingested methyl mercury is almost entirely absorbed from the gastrointestinal tract. In addition, it is neurotoxic and its loss from the body is slow. The critical parts of the body affected are the brain and nervous system. Unborn children are especially endangered because mercury is concentrated in the fetus.

Symptoms of inorganic and organic mercury poisoning are similar. They include sensory disturbances including, uncoordinated movement and impairment of hearing and eyesight, appearance of gingivitis, stomatitis, erethism, and tremor. Effects to the respiratory system include pneumonitis, bronchitis, chest pains, dyspepsia, and coughing. Ingestion of some inorganic mercurial compounds such as mercuric chloride causes irritation and corrosion of the body tissue contacted. In the congenital form cerebral infantile paralysis, mental retardation, speech retardation, salivation and malfunctions in body mobility also appear. Pathological studies showed that four to six years after poisoning there were changes in the white matter of the brain. Other changes were tissue coarseness, sclerrosis, thinning of myelin and degeneration and withering of the cerebral cortex.[1,2,3]

Unfortunately, the early symptoms of mercury poisoning resulting from chronic exposure may be ignored or attributed to other causes by the afflicted individual. Often, symptoms are thought to be linked to mental strain, and the wrong type of medical help is sought.

The organ which, in almost all instances, exhibits the highest concentration of mercury is the liver. Kidney damage may also result, which may or may not be reflected in mercury being detected in the urine.

Mercury poisoning occurs when mercury combines with certain enzymes, thus inhibiting their action. This reaction takes place because many enzymes contain sulfhydryl groups (SH). Mercury readily combines with the sulfur replacing the hydrogen and forming a covalent bond.

The antidote for mercury poisoning is BAL (dimercaprol 2,3-Dimercapto-1-propanol). It contains sulfhydryl groups which form a stable mercaptide ring which is water soluble and readily eliminated from the body.[2]

Acceptable Daily Average Intake of Mercury

In Sweden, a provisional, tolerable weekly intake of 0.3 mg of total mercury per person, of which no more than 0.2 mg should be methyl mercury, has been established. This is 0.005 mg and 0.0033 mg respectively, per kg of body weight for a 60 kg (134 lb.) person.[3] If fish were contaminated with 1.0 mgHg/kg, the average person's diet should not exceed 210 grams of this fish per week.

Concentrations of total mercury in the blood of 0.2 mg/g and in the hair of 60 mg/g may be indicative of mercury poisoning in humans. These levels correspond to an average daily intake of mercury of 0.3 mg. An average daily intake of 0.03 mg is probably safe.[3]

The EPA, in promulgating the National Emission Standard for mercury as a hazardous air pollutant, considered the total mercury exposures of the individual, the air-, water-, and food-borne burdens. Based upon a number of studies, both animal experiments and human episodes of mercury poisoning, it was concluded that 4 micrograms of methylmercury per kilogram of bodyweight per day would result in the intoxication of a sensitive adult.[5] In addition, 100 micrograms of mercury per cubic meter of air also involves a definite risk of mercury intoxication. When an "ample margin of safety" was considered, for exposures to methymercury in the diet and mercury vapor in air, it was concluded that an acceptable exposure would be 30 micrograms per day for a 70 kg man.

Levels of Mercury Found in Plants and Animals

Natural and contaminated concentrations of mercury found in plants and animals are listed in Table 1. Natural levels in fish range from 0.005 to

TABLE 1

MERCURY CONTENT OF PLANTS AND ANIMALS[a,b]

Species	Natural Level(ppm)	Observed Contaminated Level(ppm)
Fresh Water Fish	0.005 - 0.2	9.08 - 10.6
Marine Fish		
Tuna	0.050 - 0.30	2.5
Swordfish	0.18	2.4
Drifter Fish	0.010 - 0.30	1.7
Shellfish		
Crayfish	0.010 - 0.50	0.30 - 0.80
Crabs	0.020 - 0.20	1.55 - 13.4
Farm Products		
Eggs	0.005 - 0.009	
Plants		
Fruits	0.04	0.26
Wheat, Barley	0.008	0.40
Rice	0.005 - 0.32	0.24 - 2.40
Vegetables	0.001 - 0.09	0.57
Roots	0.013 - 0.08	0.18
Potato	0.003	0.23

[a]Reference 6

[b]On a dry weight basis

0.05 ppm on a dry basis. Contaminated levels range from 0.30 to 13.4 ppm. Natural levels in plants range from 0.001 to 0.32 ppm. Contaminated levels range from 0.18 to 2.40 ppm.[3]

A listing of mercury content of museum fish is shown in Table 2. A listing of mercury in Lake George fish caught in 1970 is shown in Table 3. Lake George fish data were available and served as a comparison to the museum fish data. Bioaccumulation has been occurring for decades even before major man-made discharges of mercury began entering the waterways. Lake trout caught in 1939 showed higher values for mercury than those caught in 1970. However, both specimens are well above the recommended limit of 0.5 ppm for fish.

STANDARDS AND REGULATIONS

The toxic nature of mercury and its increased levels of emission to the environment has necessitated the formulation of regulations to control discharges. To date the Environmental Protection Agency, Food and Drug Administration, and Department of Health, Education and Welfare have published standards, the latter recommending standards to the Labor Department for promulgation. Mercury is regulated by EPA for ocean dumping, its presence in pesticides and drinking water, as an emission to air, and as an emission to navigable waters. FDA regulates the amount of mercury which may be contained in shellfish. The amount of mercury in the air of any work place is regulated by the Department of Labor through OSHA through enforcement of HEW (NIOSH) recommended standards. The current standard is 0.05 g/m^3 for 8 hours. These are summarized in Table 4.[8-14]

Discharge Regulations

On March 31, 1971 the EPA listed three hazardous air pollutants, among them mercury, under Section 112 of the Clean Air Act as amended. The Administrator's judgment that they "may cause, or contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness" was the basis for the determination that they were hazardous.[15] Mercury levels in air, water and food were considered in determining safe levels and discharge rates.

The National Emission Standards for Hazardous Air Pollutants were promulgated on April 6, 1973 and amended Oct. 3, 1975. Emissions to the atmosphere of mercury from ore processing facilities and mercury cell chlor-alkali plants are not to exceed 2300 grams of mercury per 24-hour period. Emissions to the atmosphere from sludge incineration plants, sludge drying plants, or a combination of those which process wastewater treatment plant sludges are not to exceed 3200 grams of mercury per 24-hour period.

The basis for these emission levels was the result of an analysis of mercury poisoning episodes in Japan, Sweden and Iraq, indicating that 4

TABLE 2

MERCURY IN PRESERVED FISH[a]

SPECIES	LOCATION	YEAR	Hg (ppm)
Walleyed Pike	Lake Ontario	1939	0.69
Walleyed Pike	Ticonderoga Creek	1929	0.76
Small Mouth Bass	Lang Pond	1930	0.31
Landlocked Salmon	Forked Lake	1933	0.63
Landlocked Salmon	Lake George	1923	0.36
Landlocked Salmon	Lake George	1934	0.20
Lake Trout	Schroon Lake	1932	1.53
Small Mouth Bass	Beaver River	1880	0.44
Walleyed Pike	Beaver River	1880	0.47
Great Northern Pike	Lake Erie	pre-1889	0.68
Great Northern Pike	Lake George	pre-1889	0.62
Small Mouth Bass	Lake George	1900	0.41
Small Mouth Bass	Lake Erie	1900	1.87
Whitefish	Lake Huron	1919	0.39
Whitefish	Saranac Lake	1897	0.49
Small Mouth Bass	Sunapee Lake	1896	0.41
Rainbow Trout	Callicoon Creek	1912	0.69

[a] Reference 7

TABLE 3

MERCURY CONTENT OF LAKE GEORGE FISH - 1970[a]

Species	Hg (ppm)
Lake Trout	1.20
Lake Trout	1.03
Rainbow Trout	0.92
Small Mouth Bass	0.55
Small Mouth Bass	0.53

[a] Reference 7

TABLE 4. SUMMARY OF FEDERAL REGULATIONS LIMITING MERCURY[a]

AGENCY	STANDARD	RECEIVING BODY	LEGISLATIVE MANDATE	REMARKS
			Discharges	
EPA Air	2300 gms/24 hrs	Air	Section 112 of Clean Air Act Amendments (P.L. 91-604) enacted in 1970 4/6/73 Pm. 10/14/75 (revised)	Covers stationary sources which process mercury ore, or use mercury cells to produce chlorine gas and alkali metal hydroxide.
EPA Air	3200 gms/24 hrs	Air	Section 112 of Clean Air Act Amendments (P.L. 91-604) enacted in 1970 10/14/75 Pm	Covers stationary sources which incinerate or dry waste water treatment sludge.
EPA Effluent Guidelines	0.002 mg/ℓ (daily) 0.001 mg/ℓ (30-day) avg.)	Navigable waters	Sections 301, 304, 306 and 307 of Federal Water Pollution Control Act Amendments (P.L. 92-500) enacted October 18, 1972. 10/6/75 Pm	Covers mining and dressing of mercury ores and precious metals.
EPA Effluent Guidelines	0.00028 k/g/kkg (daily) 0.00014 kg/kkg (30-day avg.)	Navigable waters	Sections 301, 304, 306 and 307 of Federal Water Pollution Control Act Amendments (P.L. 92-500) enacted October 18, 1972. 3/12/74 Pm	Covers inorganic chemicals - KOH production.
EPA Toxic Substances	No discharge	streams, lakes, estuaries with flow <10cfs or lakes with area ≤ 500 ac	Section 307 of Federal Water Pollution Control Act Amendments (P.L. 92-500) enacted October 18, 1972 12/27/73 P	Under the mandate of the FWPCA amendments of 1972, EPA proposed these regulations for toxic substances. As a result of controversy which arose during the course of public hearings, the regulations were never promulgated The Toxic Substances Control Act of October 1976 superceded the above mandate. EPA is presently implementing this Act.
EPA Toxic Substances	20 µg/ℓ	fresh water bodies larger than in a) and have flow 10x ≥ waste stream	Same	Same
EPA Toxic Substances	2.0 µg/ℓ	fresh water bodies larger than a) and have a flow <10x waste stream	Same	Same

[a]References 8-14

TABLE 4. (Continued)

AGENCY	STANDARD	RECEIVING BODY	LEGISLATIVE MANDATE	REMARKS
			Discharges	
EPA Toxic Substances	100 µg/ℓ	salt water bodies larger than a) w/ flow ≥ 10x waste stream	Same	Same
EPA Toxic Substances	10.0 µg/ℓ	salt water bodies larger than a) with flow <10x waste stream	Same	Same
EPA Toxic Substances	1.62 lb/day	lake regardless of receiving water flow	Same	Same
EPA Toxic Substances	27.0 lb/day	estuary regardless of flow	Same	Same
EPA Toxic Substances	32.4 lb/day	coastal waters regardless of flow	Same	Same
EPA Ocean Dumping	0.75 mg/kg	oceans	Sections 403 and 404 of Federal Water Pollution Control Act Amendments (P.L. 92-500) enacted October 18, 1972 and Title I of the Marine Protection, Research and Sanctuaries Act enacted October 23, 1972 (P.L. 92-532). 10/15/73 Pm	Mercury and its compounds may not be present in any solid phase of a waste greater than 0.75 mg/kg.
EPA Ocean Dumping	1.5 mg/kg	oceans	Same	Total concentration of mercury in liquid phase of a waste does not exceed 1.5 mg/kg.

TABLE 4. (Continued)

AGENCY	STANDARD	RECEIVING BODY	LEGISLATIVE MANDATE	REMARKS
			Discharges	
EPA Hazardous Substances	Harmful quantity = 1 lb	any media	Section 311 of the Federal Water Pollution Control Act Amendments (P.L. 92-500) enacted October 18, 1972. 12/30/75 P	This regulation classifies Hg on the basis of toxic to aquatic animal life. It falls into the most toxic subpart because it has an LC_{50} of <1ppm. Harmful quantity is designed as the smallest common commercial container size. For this class of substance this container was found to be 1 lb (454 k). This reg. treats all releases as accidental and on an intermittent basis. It is possible to calculate a penalty payment on the basis of toxicity and amount released. It covers mercuric acetate, mercuric cyanide, mercuric nitrate, mercuric sulfate, mercuric thiocyanate and mercurous nitrate.
EPA Pesticides	Cancelled cmpds containing Hg	any media	Section 13 of the Federal Insecticide, Fungicide, and Rodenticide Act enacted in 1947 and amended 1959, 1961, 1964, 1972 and 1975.	As a consequence of hearings held by EPA in Sept. 1975, all pesticides containing Hg except those listed below were cancelled: 1. H_2O based paints within can preservatives 2. Snow mold on golf course greens 3. Dutch elm disease 4. Outdoor fabrics (not indoor or clothing) for mildew protection 5. Brown mold on lumber 6. Seed treatment cancelled effective 8/31/78 7. Against summer diseases cancelled effective 8/31/78
			Ambient	
HEW NIOSH	0.05 mg/m^3 for an 8-hr. work day	air	N/A. 1973	Suggested standard published in criterion document transmitted to Department of Labor.

TABLE 4. (Concluded)

AGENCY	STANDARD	RECEIVING BODY	LEGISLATIVE MANDATE	REMARKS
			Ambient	
EPA Quality Criteria for Water	2.0 µg/ℓ for domestic water supply (health)	water supply	N/A	Standards exist as criteria. Formulated on basis of toxicity studies on aquatic organisms.
	0.05 µg/ℓ for fresh water aquatic life and wildlife	fresh water		
	0.10 µg/ℓ for marine aquatic life	salt water		
EPA Drinking Water	0.002 mg/ℓ	drinking water	Sections 1412, 1414, 1415, and 1450 of the Public Health Service Act as amended by the Safe Drinking Water Act (P.L. 93-523). 12/24/75 Pm	These regulations exist as interim primary regulations.
FDA Shellfish	0.50 ppm	shellfish	Sections 306, 402, 406 and 701 of the Federal Food, Drug, and Cosmetic Act as amended. 12/6/74 P	

NOTE:

P - Proposed
Pm - Promulgated

micrograms of methylmercury per kilogram of body weight per day would cause mercury intoxication of a sensitive adult. The EPA, in arriving at an ample safety margin, assumed exposure to both methylmercury in the diet and mercury vapor in air were equivalent and additive. Based on further assumptions of average mercury levels found in the diet together with the average inhilation rate of 20 cubic meters of air per day, the air could not have an average daily concentration greater than 1 $g/m.^3$ The regulations were aimed at those industries which were found by EPA to emit mercury that could cause the ambient concentration of 1 g/m^3 to be exceeded. The emission limits were therefore established for those industries at levels which would not cause that ambient concentration to be exceeded.

The limit for sludge incineration and drying plants is based on maintaining an average ambient mercury concentration of 1 g/m^3 over a 30 day period. With an assumed average emission rate of 1.5 grams of mercury per ton, and with wet scrubbers being used, a 2132 tons-per-day (dry solids) plant would approach the limit. However, there are no known existing or anticipated wastewater plants which approach this size. The average emission rates were based on EPA tests of 42 treatment plant sludges.[15,16]

On March 12, 1974, guidelines were promulgated by EPA covering discharge to navigable waters of wastes from the manufacture of inorganic chemicals. That subcategory which specifically limits mercury is the production of potassium hydroxide (KOH). The daily allowable discharge is 0.00028 kg Hg/kkg of product. The 30-day average is 0.00014 kg/kkg of product.

On October 6, 1975, guidelines were promulgated by EPA covering discharges to navigable waters of wastes from the areas in which mining and dressing of mercury occurs. These guidelines were issued under the authority of the Federal Water Pollution Control Act as amended by the Federal Water Control Act Amendments of 1972. The daily limit is a concentration of 0.002 mg/l in the discharge stream with the 30-day average being 0.001 mg/l.

Toxic substances standards were proposed December 27, 1973 by the EPA in accordance with section 307(a) of the Federal Water Pollution Control Act Amendments of 1972. These standards have not yet been promulgated. They cover mercury and all mercury compounds. Toxicological data, hydrodynamic data, margins of safety, and calculations of acute and chronic limitations were considered in setting the proposed standards. Standards are expressed in terms of total weight discharged and weight discharged per unit of flow. The proposed standards limit the discharges to streams, lakes, estuaries, and coastal waters and are based on flow and area of the receiving body. The Toxic Substances Control Act of October 1976 supercedes these proposed standards. No standards have been promulgated under the Act thus far.

Standards regulating the discharge of materials into the oceans were promulgated in the Federal Register on October 15, 1973. These standards are to prevent or strictly regulate the dumping or other discharge into the ocean waters of any material in quantities which would adversely affect

human health, welfare or amenities, the marine environment, ecological systems, economic potentialities, as well as plankton, fish, shellfish, wildlife, shorelines, or beaches. Mercury and its compounds are not to be present in any solid phase of a waste in concentrations greater than 0.57 mgHg/kg and the total concentration of mercury in the liquid phase of a waste are not to exceed 1.5 mgHg/kg.

Standards for hazardous materials were proposed in the Federal Register on December 30, 1975, under Section 311(b) (2) (A) of the Federal Water Pollution Control Act Amendments of 1972. This regulation classifies mercury on the basis of toxicity to aquatic animal life. It falls into the most toxic designation because it has an LC_{50} of <1 ppm. An LC_{50} is the mean lethal concentration, or the concentration at which 50 percent of the test species die. The maximum amount which may be released to the aquatic environment as a result of an accident is defined as the contents of the smallest commercial container size. For this class of substances, this container was determined to be 1 lb. (0.454 kg). This regulation treats all releases as accidental and on an intermittent basis. Penalty payments are calculated on the basis of toxicity and amount released. The substances covered are mercuric nitrate, mercuric acetate, mercuric cyanide, mercuric sulfate, mercuric thiocyanate, and mercurous nitrate.

As a result of hearings held by EPA in September, 1975, all pesticides containing mercury except those for the purposes listed below were cancelled.

(1) Preservatives for water based paints

(2) Prevention of snow mold on golf course greens

(3) Prevention of Dutch elm disease

(4) Protection against mildew on outdoor (not indoor) fabrics

(5) Prevention of brown mold on lumber

(6) Seed treatment (cancellation effective August 31, 1978)

(7) Prevention of summer disease (cancellation effective August 31, 1978).

Ambient Regulations

NIOSH has suggested standards for the control of mercury in the work place. These standards were published in the form of a criterion document transmitted to the Department of Labor in 1973. The suggested minimum acceptable level is 0.05 g/m^3 of air during an eight-hour work day.

EPA issued quality criteria for mercury concentrations in water.[11] Three different types of water were covered--domestic water supply, fresh

water, and marine water. The limits were based upon known toxic levels in humans and toxicity studies on several species of fish and invertebrates. Of special concern was the ability of some organisms to methylate mercury. The domestic water supply criterion is 2.0 g/l.

The standard for levels in water was based on the premise that the FDA established guideline for edible fish at 0.5 mg/kg of body weight should not be exceeded. A mercury concentration factor of 10,000 for certain fresh water species has been found. The level for fresh water was reached by dividing the FDA standard of 0.5 mg/l by 10,000 to yield 0.05 g/l.

The natural level for sea water was found to be about 0.1 g/l of mercury. This was an order or magnitude below that which represents a threat to selected species of marine organisms. Thus, 0.1 g/l became the recommended criterion.

Drinking water standards were promulgated December 24, 1975, in accordance with sections 1412, 1414, 1415, and 1450 of the Public Health Service Act as amended by the Safe Drinking Water Act (P.L. 93-523). This standard, 0.002 ppm, was based on a consumption level of two liters of water per day. This amounted to a daily intake of 0.004 mg. Those public water systems covered must serve at least fifteen service connections used by year-round residents or serve at least twenty-five year-round residents.

On December 6, 1974, the Food and Drug Administration published in the Federal Register the action level for mercury in fish and shellfish. Mercury in edible fish tissue is almost completely methylmercury. In shrimp and lobster, limited testing indicated that mercury was also in the methylated form. However, there were no analytical procedures that are capable of measuring levels of methylmercury necessary for regulatory purposes. Consequently, the standard was expressed in terms of total mercury. An action level of 0.50 ppm was established for mercury in fish and shellfish (mollusks and crustaceans), both raw and processed.

SECTION 6

IMPORTANCE OF POWER PLANT EMISSIONS

ESTIMATE OF MERCURY EMISSIONS FROM POWER PLANTS

Fossil fuel-fired power plants contribute mercury to the environment through the combustion process. Since the composition of oil and coal i cludes a number of elements and compounds, including mercury and volatile mercury compounds, the combustion process releases mercury in addition to other elements.[17] Coal and oil fired power plants accounted for 11.4 x 10^{11} Kwh or almost 60 percent of the total power generated in 1975, of which coal fired plants provided 75 percent of that, or 8.5 x 10^{11} Kwh. The fossil fuel requirements to produce that power were 4 x 10^{8} tons of coal and 5 x 10^{8} barrels of oil.[18] The coal and oil consumed and the electric power which was generated were approximately the same in 1974 as in 1975.[19] The consumption of these fuels by state, geographic region, and nationally are shown in Table 5. We selected 1974 data for this report because that year's data was the most complete set available.

The East North Central and East South Central states generated about 32 percent of the net power in 1974 from 35 percent of the approximately 968 fossil fuel-fired steam electric plants, with 92 percent and 93 percent of the Btu respectively, derived from coal combustion. This accounted for about 50 percent of the 393.6 x 10^{6} tons of coal used in power plants that year. Similarly, the New England, Middle Atlantic, and Pacific states generated about 21 percent of the net power from 20 percent of the power plants with 87 percent, 42 percent and 56 percent of the Btu, respectively, derived from the combustion of oil.

The mercury found in these fuels can vary substantially depending on the source of the fuel. Mercury content of coals from different sources has been measured by several investigators.[21-25]

Table 6 shows the variation in the mercury content of 800 coal samples, summarized according to geographic distribution. The data presented are averages of all the coal samples tested by the Geological Survey from each of the states within a region.[25] Based upon the coal production in each of those regions, Appalachian coal, amounting to 66 percent of the total coal produced in 1974, could account for about 74 percent of mercury from this source. This compares with Midwest coal, amounting to 16 percent of the production while accounting for about 11 percent of the mercury estimated to be present in coal.

TABLE 5. SUMMARY OF COAL AND OIL USAGE FOR ELECTRIC POWER GENERATION FOR 1974[a]

Region	No. of Plants[b]		Net Generation[c] (10^6 KWh)	Fuel Use[d] Coal (10^3 tons)	Fuel Use[d] Oil (10^3 barrels)	% of Total Btu Coal	% of Total Btu Oil	Net Generation[e] Coal	Net Generation[e] Oil	% of Fuel Used in U.S. Coal	% of Fuel Used in U.S. Oil
New England	54		46,777.9	2,137	70,808	11	87	5,145.6	40,698.8	0.54	14.86
Connecticut		13	14,850.6								
Maine		6	2,197.5								
Massachusetts		23	25,122.5								
New Hampshire		5	3,286.8								
Rhode Island		4	1,195.6								
Vermont		3	134.9								
Middle Atlantic	96		174,895.0	44,681	126,790	56	42	97,941.2	73,455.9	11.35	26.62
New Jersey		18	25,221.6								
New York State (incl NYC)		36	62,390.9								
N.Y.C.		(15)	(33,576.4)								
Pennsylvania		42	87,282.5								
East North Central	184		301,082.1	132.754	24,727	92	5	276,995.5	15,054.1	33.73	5.19
Illinois		39	69,300.9								
Indiana		32	56,092.7								
Michigan		37	57,152.1								
Ohio		47	96,990.9								
Wisconsin		29	21,545.5								
West North Central	182		94,461.6	36,939	2,942	67	2	63,289.3	1,689.2	9.39	0.62
Iowa		37	12,861.6								
Kansas		35	16,700.4								
Minnesota		44	16,239.4								
Missouri		28	35,763.1								
Nebraska		19	6,478.1								
N. Dakota		12	5,742.4								
S. Dakota		7	676.6								
South Atlantic	130		285,421.9	78,381	140,779	63	30	179,815.8	85,626.6	19.92	29.55
Delaware		5	6,350.0								
D. C.		2	2,301.4								
Florida		42	65,347.5								
Georgia		13	32,354.6								
Maryland		11	24,941.6								
N. Carolina		14	50,684.6								
S. Carolina		17	16,341.0								
Virginia		13	26,128.1								
W. Virginia		13	60,953.1								
East South Central	57		150,875.1	63,972	8,763	93	3	140,313.8	4,526.3	16.25	1.84
Alabama		14	43,192.0								
Kentucky		21	51,120.8								
Mississippi		14	11,080.7								
Tennessee		8	45,481.6								
West South Central	140		212,469.2	5,197	20,772	3	6	6,374.1	12,748.2	1.32	4.36
Arkansas		10	7,528.8								
Louisiana		23	37,155.3								
Oklahoma		19	28,986.8								
Texas		88	138,798.3								
Mountains	80		70,473.8	26,577	9,906	67	8	47,217.4	5,637.9	6.75	2.08
Arizona		12	11,672.1								
Colorado		20	13,851.6								
Montana		4	1,271.6								
Nevada		6	12,099.0								
New Mexico		18	19,918.6								
Utah		11	2,976.7								
Wyoming		9	8,684.2								
Pacific[f]	45		673.2	2,925	70,893	9	56	6,720.6	41,817.0	0.74	14.88
California		38	70,458.8								
Washington		7	4,214.4								
U.S. TOTAL	968	968	1,411,129.8	393,563	476,380	58	20	823,813.3	281,452	99.99	100.00

[a]Reference 19

[b]Includes electric generating plants which are fueled by coal, oil and gas.

[c]The amount of power generated, less the amounts consumed by the power plant for their own use. The net generation amounts to approximately 47% of the installed capacity, which is the maximum generator nameplate rating.

[d]May be as much as 5% high in comparison with Federal Power Commission estimate. Ref. 20

[e]Based upon the relative percentage of the average Btu content for each fuel assuming the combustion efficiency of both oil and coal are the same.

[f]Oregon is not included as the 2 plants listed for that state were both gas fired.

TABLE 6. MERCURY CONTENT OF COALS

Region	Average Mercury Content[1]		Coal Production[2]		Total Mercury
	ppm	10^{-9} tons/ton	10^{6} tons	% of Total	(tons)
Appalachia	0.23	230	408	67	93.8
Midwest	0.14	140	97	16	13.6
Gulf	0.18	180	20	3	3.6
N. Great Plains	0.09	90	43	7	3.9
Rockies	0.06	60	17	3	1.0
Other	0.42	420	25	4	10.5
Total	0.21[3]	208	610		126

[1]Reference 25

[2]Reference 26, 27; 1974 data. Anthracite, Bituminous, and Lignite for all uses.

[3]Weighted averaged based on % of coal produced.

The amounts of mercury in the coal from the different regions are based upon averages of channel and core samples. Variations can occur within a coal seam which may assay either significantly higher or lower than the average. Based upon the averages, however, the total amount of mercury available to be released to the environment was approximately 126 tons from the 610×10^6 tons mined. This amount of coal mined was about 2 percent greater than in 1973, according to available data.

The total tonnage of coal produced was used not only for electric power generation, but for coke and gas plants and other uses. Distribution figures for 1974 showed that of a total coal production (bituminous coal and lignite) in 1974 of 610×10^6 tons, about 65 percent was used by electric utilities, 16 percent in coke and gas plants, while 19 percent went to all other uses.[28] The oil embargo imposed by the Organization of Petroleum Exporting Countries in the last quarter of 1973 sparked interest in the use of coal. It is assumed that the conversion of oil-fired plants to dual or coal-fired use did not appreciably increase the electric utilities share of coal consumption until late 1975. This would be due to the time lag in both the regulatory agency approval process and the physical conversion time. Assuming a 10 percent overall increase in the share of coal used by electric utilities from 1973 to 1975, the mercury contained in the utilities' coal for 1975 is approximately 90 tons.

The mercury content of fuel oil has been shown to vary from 0.002 ppm to as much as 10 ppm.[17,21] An average mercury concentration which may be applied to fuel oil is 0.1 ppm, which may also be expressed as 32×10^{-5} pounds per barrel (1 barrel equals 42 U.S. gallons). This is an average of values for domestic and foreign oil.[21] Table 7 shows the distribution of oil by region for use in electric power generation in 1974. The Middle Atlantic and South Atlantic regions, which together generated one-third of net generated electric power in the United States, accounted for 65 percent of all the fuel oil used for electric power generation. Assuming the average concentration of fuel oil to be 0.1 ppm this amounted to 42.7 tons of mercury for the year 1974. The amount of mercury present in the oil used for all electric power generation in 1974 in the United States was approximately 76 tons.

The combustion of oil produces about 2.9 times as much mercury, for release to the atmosphere, as does coal in generating the same net kilowatt-hours of electricity based on calculated average mercury content of each fuel and accepted fuel conversion rates.[19] If power plants would be covered by the EPA maximum mercury emission standard of 3200 grams per day, established for selected sources, an uncontrolled 1,000 MW_e oil-fired power plant would emit about 141 percent of the maximum allowable emissions, while a coal fired plant of that size would emit about 50 percent of the limit. Power plants are not covered by the regulation.

The Four Corners power plant in New Mexico was estimated to require a maximum mercury emission rate of 9.57×10^5 g/day before the monthly

TABLE 7. MERCURY CONTRIBUTION FROM ELECTRIC POWER GENERATION BY REGION, 1974

Region	COAL				OIL		Total Emissions to Stack Gas (tons)
	Usage[a] (10^3 tons)	Total Hg Content[b] (tons)	Hg Emitted to[c,f,g] Stack Gas (tons)	Hg in Ash[c] (tons)	Usage[a] (10^3 barrels)	Hg Emitted[d,e,f,g] to Stack Gas (tons)	
New England	2,137	0.44	0.40	<0.1	70,808	11.3	11.7
Middle Atlantic	44,681	9.3	8.4	0.9	126,790	20.2	28.6
East North Central	132,754	27.6	24.8	2.8	24,727	3.9	28.7
West North Central	36,939	7.7	6.9	0.8	2,942	0.5	7.4
South Atlantic	78,381	16.3	14.7	1.6	140,779	22.5	37.2
East South Central	63,972	13.3	12.1	1.2	8,763	1.4	13.5
West South Central	5,197	1.1	1.0	0.1	20,772	3.3	4.3
Mountain	26,577	5.5	5.0	0.5	9,906	1.6	6.6
Pacific	2,925	0.6	0.5	0.1	70,893	11.3	11.8
Total U.S.	393,563	81.8	73.8	9	476,380	76.0	149.8

[a] From Table 5

[b] From calculation of a weighted average mercury content of U.S. coal, from Table 6, of 208×10^{-9} tons Hg/ton coal.

[c] Based upon 90% emitted in the stack gas, and 10% remaining found in the ash. Ref. 30-33

[d] Based on an average mercury content of 31.9×10^{-5} lbs. Hg/bbl., 0.1 ppm. Ref. 17, 21

[e] Assuming all mercury in the oil is emitted in the stack gas.

[f] This is the amount of mercury which is estimated to enter the stack gas. Scrubbing equipment in the line, with the exception of an electrostatic precipitator, may reduce the amount of mercury ultimately released to the atmosphere.

[g] Based upon uncontrolled emissions.

average ambient concentration of 1.0 g/m^3 would have been exceeded.[29] This ambient concentration was the guideline for the emission standard. If an ambient concentration were to be the measure of emission level, then the above 1000 MW_e plants for the same location and conditions, are emitting 1.4 percent and 0.5 percent of the guideline ambient concentration.

Utilities burned 3×10^{12} scf of gas to generate electricity in 1974.[19] While gas, a fossil fuel, has been estimated to have an average mercury concentration of 40 ppb, we have not included the approximately 5 tons of mercury which may be attributable to this fuel. The processing of the gas to eliminate hydrogen sulfide, prior to insertion into the pipeline system, as well as the reported formation of insoluble mercury compounds (e.g. sulfides) on pipeline walls may reduce the mercury concentration in delivered gas to 1 to 2 ppb.[30]

The type of fuel as well as the configuration of the stack gas control system will ultimately determine the amount of mercury which actually enters the air. The combustion of coal emits 90 percent of the mercury content into the stack gas and leaves 10 percent remaining in the ash. All of the mercury, however, is considered to enter the stack gas in the combustion of oil.[30-33] The widespread use of scrubbers for gaseous and particulate emissions may remove mercury from the stack gas. Few studies have been done, and those quite limited, to determine the removal of mercury by scrubbers and precipitators. The use of electrostatic precipitators was shown to have no effect on mercury emissions.[34,35] Sulfur dioxide scrubbing systems, however, have been shown to remove about 1/3 of the mercury from the stack gas.[30] However, the worst case would be to assume that all the mercury in the stack gas (90 percent of that in coal and 100 percent of that in oil) is emitted to the atmosphere.

RELATIVE IMPORTANCE OF POWER PLANT EMISSIONS

Mercury emissions from power plants is but one source of mercury to the environment. This section will identify and define the extent of the other sources, natural as well as anthropogenic, and place electric power generation in perspective as a source of mercury.

Identification of Other Sources of Mercury Emissions

Mercury enters the environment (air, land, and water) from mining operations, utilities and other unregulated sources, manufacturing, consumption of mercury and its derivatives, and through natural release of mercury from the earth. The varied applications of mercury are as a result of its unusual combination of useful properties, such as liquidity at ambient temperatures, high surface tension, uniform volume expansion, good electrical conductivity, high density, chemical stability, alloy capability, and toxicity of its compounds.

Mercury Mining and Smelting--

Mercury mines are an obvious source of mercury pollution. In 1973 there were 24 producing mines, 35 percent fewer than in 1972. By the end of 1973 six remained active while seven mines reported production only from dumps, cleanup operations, or as a by product. Seven other had production levels not exceeding 10 flasks (1 flask = 76 pounds). Of the total 1973 production of 2,171 flasks, 83 percent came from the 5 mines with production levels greater than 100 flasks.[35] The first quarter of 1974 found only five operating mines, compared to 149 producing mines in the boom of the 1960's.

The refining of low-grade ores provides an additional source of mercury. Beneficiation (concentration) of mercury ores takes on increased importance with a depletion of high-grade ores. Beneficiation methods include hand sorting, crushing, screening, jiggling, tabling, and flotation. Flotation is the most efficient, producing a 25-50 percent concentrate, with mercury recovery of 90 percent. The conventional process for extracting mercury from ores, called roasting, is a distillation process in which the ore is heated in a furnace or retort to vaporize the mercury, after which it is condensed to the liquid metal. Recovery averages about 95 percent for furnace plants and 98 percent for retort operations. The resulting product is 99.9 percent pure.[37]

Copper Smelting--

Mercury is commonly found with other mineral deposits such as lead, copper, and zinc. The mining and smelting processes for these metals are also a source of mercury emissions to the environment. Among these, copper smelting may produce considerable quantities of mercury.

About 1/4 of the world's copper is produced in the United States. Copper is mined in eight states with Arizona accounting for about half of the U.S. production. Approximately 225,000 tons of ore was processed in 1973.[30]

Copper is generally produced from open pit mined ores. The principal steps involved are mechanical concentration, smelting, conversion to blister copper, and electrolytic refining. Some mercury would be emitted during mining as a result of degassing when the mineral deposit is exposed. Mercury has the highest probability of being emitted from pyrometallurgical processes, that is, where high temperatures would drive off mercury as vapor. Smelting is carried out in a reverberatory furnace or the newer electric furnace. The reverberatory furnace operates at a temperature of about 1480°C, at which point almost all the mercury in the ores would be released. The gases from the furnace are generally passed through scrubbers, which would ultimately affect the amount of mercury actually released to the environment.

Chlor-Alkali Manufacturing--

Chlor-Alkali manufacturing is another source of mercury in the environment as a result of the consumption of large quantities of mercury. Approximately 16 million tons per year of chlorine (gas and liquid) were produced in the United States in 1973 and 1974.[38] In 1973 the chlor-alkali industry consumed 24 percent of the mercury used in the United States (almost 1 million lbs).[30] A principle method of producing chlorine and caustic soda (NaOH) is by the electrolysis of brine, where the cathode is flowing mercury. Known as the mercury cell, it is the most widely used process in the industry, the other being the diaphragm cell.[38,39] Five plants in the United States use the Downs process (fused salt).[28] Of the 69 plants in the U.S., 27 use the mercury cell exclusively or in conjunction with the diaphragm cell. The mercury cells accounted for approximately 22 percent of the total installed chlorine production capacity in the U.S. in 1975, a decrease of 3 percent from 1973 and 1974 figures.[38]

The mercury cell technique, for the production of chlorine and NaOH from brine (a 25 percent NaCl solution), used an electrolyzer and a decomposer. In the electrolyzer an electric current is conducted through the brine by closing the loop between an anode and a flowing mercury cathode. Chlorine is liberated at the anode and a liquid alkali metal amalgam (NaHg) is formed with the flowing cathode. This amalgam is cycled through the decomposer where it is reacted with water to form caustic soda (NaOH) and hydrogen gas. Excess mercury is removed and the remaining mercury is recycled.[30,40] Mercury losses to the environment occur throughout the process.

Manufacture of Mercurials--

The manufacture of mercury compounds includes organic and inorganic mercurials which are used for agriculture, medicinals, catalysts, paint and pharmaceuticals. About 20 percent of the United States consumption of mercury in 1973 was in this manufacturing category. The consumption of the mercurials accounted for about 400 tons in 1973, with 70 percent of that being used for paint. Agricutural consumption includes fungicides and bactericides for industrial purposes. Mercury is used in paints for mildew-proofing and antifouling. Mercury compounds used as catalysts are used in the synthesis of both vinyl chloride monomer (VCM) and anthraquinone dyes. They also find use in foaming urethane in place.

Mercurial production is generally a batch operation. Most manufacturing facilities are located in New Jersey. Losses of mercury from the production of mercurials is primarily to water with minor quantities emitted to air and land. The losses from the use of manufactured catalysts are primarily to land.

Battery Manufacturing--

Battery manufacturing consumed about 30 percent of the mercury used in the United States in 1973. Most losses occured as a result of batteries

being discarded by the consumer. Approximately 92 percent of this went to landfills with 8 percent going to public incineration. Of the seven types of batteries in which mercury was used, three comprised 99.5 percent of the mercury losses in 1973. These were the zinc-carbon dry cell, the alkaline-manganese dioxide dry cell, and the Ruben cell. As of 1973 there were 35 plants which manufactured these three types of batteries.[41]

The Zinc-Carbon Dry cells use mercury primarily as a paste applied to paperboard separators. The major losses of mercury during the manufacture of this type of battery occur with the disposal of rejected batteries in landfills. In addition, since their recycling is uneconomical, the ultimate disposal by the consumer, mostly to landfills, represents a significant loss of mercury.

Mercury is used as the anode, in amalgamation with powdered zinc, in the Alkaline-Manganese Dioxide Dry Cell. The major losses with this type are the same as with the previous type of battery.

The Ruben Mercury batteries use an amalgam of zinc and metallic mercury as the anode, while red mercury oxide pressed with graphite is the cathode. Losses are minimal during manufacturing. However, the rejected cells are processed to reclaim mercury. The recovery process involves incineration in a furnace, with the residue going to a landfill. Most losses from this source, as previously, are associated with consumers discarding batteries.

Electric Lamp Manufacturing--

Mercury has been used in electric lamp manufacturing, namely the fluorescent, mercury vapor, metal halide, and high-pressure sodium types. About 95 percent of the mercury used in such manufacturing is for fluorescent lights. Most losses went to landfills with the remainder into the air. The greatest losses occured from bulbs discarded by consumers. Out of approximately 69 United States plants manufacturing electric lamps in 1973, 47 manufactured mercury lamps. In 1973 the industry consumed approximately 2.3 percent of the mercury used in the United States (almost 48 tons.)[42]

A typical fluorescent lamp manufacturing process involves the injection of metallic mercury, starting gas (usually argon), and other materials into a quartz tube, which is then sealed. About 5 percent of the losses during manufacturing are due to spilling and breakage.

Industrial Instruments Manufacturing--

Industrial instruments manufacturing, primarily switchgear and switchboard apparatus and mechanical measuring and control instruments consumed approximately 13 percent of the mercury used in the United States in 1973.[42] This represented an estimated 81 percent of mercury used in all

instrument manufacturing.[30] Metallic mercury is the primary form of mercury used in this industry. The reason for its use are primarily its properties of remaining liquid at ordinary temperatures, high electrical conductivity, excellent high thermal conductivity, and regular thermal expansion. Typical of the measuring and control instruments are the mercury-in-glass thermometer, thermostats, thermoregulators, manometers, barometers, navigational devices and medical instruments (blood CO^2 analyzers, etc.). More than half of the mercury used in the instrument industry was recycled or reclaimed as a result of manufacturing practices and industrial consumers whose equipment is traded in and/or serviced.

The primary manufacturing operations, for this entire classification in which mercury is lost to the environment are the filling process and testing and storage. During the filling process, when the instruments are loaded with premeasured amounts of mercury, the losses occur as a result of spillage and volatilization. Testing and storage losses occur for similar reasons as well as during cleaning instruments. However, considerable losses occur as a result of consumer discarding of devices containing mercury.

Paint Manufacturing--

The paint manufacturing industry accounted for 14% of the mercury used in 1973.[42] Only a small quantity was used for mildew-proofing substances, with the remainder being used for paint additives. Phenylmercuric compounds, especially phenylmercuric acetate and phenylmercuric oleate, are used in latex and solvent paints as a bactericide and a fungicide. These compounds had found wide use in antifouling paints. However, toxic effects on living organisms have reduced or eliminated their use in marine antifouling paints. As of 1973 there were almost 2,300 paint manufacturers of which 30 accounted for approximately 90% of the manufactured product value.[30]

Paint is manufactured by a batch process, with the ingredients mixed in vessels whose capacity ranges from a few hundred to several thousand gallons. Mercury is lost both as a result of bad batches and from cleaning of the vessels. These losses are to land, water, and air. Smaller manufacturing plants tend to dump wastes down the sewer. Other mercury losses during manufacturing occur from spills and volatilization. Final consumption accounts for the major loss of mercury as a result of volatilization following application.

Agricultural Consumption--

The agricultural use of organomercurial pesticides has been drastically curtailed as a result of EPA pesticide actions and anticipated actions. The major organomercurial has been phenylmercuric acetate (PMA), replacing the more effective alkylmercurials. This source of mercury to the environment occurs mostly from the land after the planting of mercury-treated seeds. Compared with the alkylmercurials, the lack of affinity for soil components of PMA allows for deeper penetration into the soil, where its solubility

permits leaching. Additional losses occur through ingestion by wildlife and man, as well as volatilization from the soil. Mercury emissions to water occur from washing of equipment and trucks transporting treated materials. Non-agricultural pesticide use, for the turf industry, also contributes mercury to the air as a result of spraying and vaporization following application. Surface runoff creates an additional source of mercury to water in nonagricultural uses because of the increased frequency of watering.

Pharmaceuticals--

The pharmaceutical industry has used mercury compounds in antiseptics, diuretics, and skin preparations; for sterilization of instruments; and as preservatives in cosmetics and soaps. The use of mercury in this industry has declined over the years due to availability of effective non-mercurial substitutes and the toxicity of mercury. Production losses to the environment come from disposal of residues in landfills. There are also contributions to the air and water, the latter as a result of washing off the body or in human wastes.

Laboratory Consumption--

Another source of mercury is the laboratory, which uses metallic mercury and mercurial compounds for reagents, indicators, use as a sealer and in vacuum pumps, for radioactive diagnosis, and as a tissue fixative. Mercury from laboratory use is emitted to the air as a result of incineration of bandages and supplies, and to the water as a result of flushing away fixative solutions, spills and cleansing laboratory apparatus. The remainder is lost to the land by disposal. More than half of the mercury used in this general application is recycled.

Dental Applications--

The use of mercury in dental applications provides an additional source to the environment. The manufacturing of mercury amalgam for fillings uses approximately 4 percent of the total mercury consumed in the United States.[30] The process involves combining a silver-tin alloy (powdered) with metallic mercury. The ingredients are placed in a mortar within a capsule, which is then vigorously shaken. The resulting metallic putty, used to fill the cavity, is condensed and polished, with the excess amalgam removed during the condensing process. Losses can occur through vaporization from open or poorly closed storage containers or from spillage. Rinsing of the patient's mouth causes mercury to enter the wastewater system.

Municipal Wastewater Treatment--

Municipal waste treatment plants collect effluents from both residential and industrial users. The mercury found in the waste stream emanates from those manufacturing and end use areas previously discussed. As a result of

the treatment processes in use, mercury can enter the receiving waters or can be emitted to land through disposal of sludge. If sludge incineration is used as an ultimate disposal method then mercury is emitted to the air.

Municipal Solid Waste Disposal--

Municipal solid waste disposal systems provide for the collection, processing, and ultimate disposal of solid wastes. The ultimate disposal methods are landfill or incineration. As a result of widespread use of mercury, mercury is found in the leachate from landfills as well as incinerator particulate emissions.[42,43] There are over 18,500 landfill sites and almost 200 municipal incinerators operating.[30]

Natural Sources--

In addition to the anthropogenic sources, nature remains a major source of mercury to the environment. The natural occurrence of mercury in the earth's crust is the source from which mercury vaporizes from the land surface and leaches out into ground water and ultimately to surface water and its sediments.

Quantitative Estimate of Emissions from Other Sources

In order to make an assessment of the mercury emissions from power plants it is necessary to know what the various sources of mercury are and the extent of their contribution to the environment. Table 8 shows the estimated losses on a national basis, to all media from these sources for 1974.

The amount of mercury mined and the amounts of mercury consumed by the various "Manufacturing and Processing" categories were obtained from Bureau of Mines data.[45] The distribution of mercury losses to air, land, and water was based upon the URS study of these sources in which they characterized the losses by process.[30] Since their study was for 1973, we substituted 1974 mercury inputs to these industries and used their percentage losses to arrive at the data in Table 8. Similarly, we used the ratios of mercury which they found, after the manufacturing process, to remain in the products for consumption, and applied them to 1974 data. The data for mercury losses by utilities were derived in this report.

The URS report was used as a base because it was believed that the data base and depth of study was the most complete information available. Their assumptions appeared to be valid, except where we made note in this report.

Mining and Smelting--

Mercury production from mining has declined over the years from a high of 1125 tons in 1969 to 83 tons in 1974. The 1974 figure was approximately 2 tons more than in 1973. The 83 tons produced were from 18 mines located in western states. It was estimated that 2 percent to 3 percent of the mercury was lost through stack emissions, on an industry-wide basis.[46]

TABLE 8. ESTIMATED MERCURY LOSSES TO THE ENVIRONMENT, 1974[a]

	Mercury Consumed[b] (Tons)	Mercury Losses (Tons)				Losses Relative to Power Plant Losses[d]			
		Air	Land	Water	Total	Air	Land	Water	Total
Mining & Shelting									
Mercury	83[c]	2	7	-	9	0.01	0.97	-	0.06
Copper	105[e]	58[e]	44[e]	3[e]	105	0.4	5.5		0.7
Other	-	11[e]	3[e]	1[e]	15	0.07	0.4		0.09
Subtotal (% of total for media)	188	71(11%)	54(4%)	4(2%)	129(6%)				
Unrelated Sources									
Utilities (Oil & Coal)	-	150[g]	8[g]	-	158	1	1	1	1
Other unregulated[h]	-	60 [a,k]	42 [a,k]	? [a,k]	104 [k]	0.4	5.3		0.7
Waste Treatment	-	26 [a,k]	39 [a,k]	65 [a,k]	130 [k]	0.2	5		0.8
Incineration	-	41[a]	4.6[a]	-	45.6	0.3	0.6		0.3
Subtotal (% of total for media)	-	277(45%)	93.6(7%)	67(39%)	437.6(20%)				
Manufacturing & Processing									
Agriculture	37	-	0.7	0.8	1.5	-	0.1		0.009
Catalysts	49	-	-	0.2	0.2	-	-		0.001
Dental Preparations	115	2	-	-	2	0.1	-		0.01
Electrical Apparatus Batteries	748	-	3.5	-	3.5	-	0.4		0.02
Lamps		0.1	2.0	-	2.1	0.007	0.25		0.01
Chlor-Alkali Prep.- Electrolytic	642	22	349	3	374	0.15	43.5		2.4
Industrial Controls & Instruments									
Control Inst.	191[i]	0.1[a]	1.8[a]	-[a]	1.9	0.0007	0.2		
Switches and Relays	45[i]	0.1	1.1[a]	[a]	1.1	0.0007	0.1		
Paint:									
Antifouling	0.2	0.0002	0.0017	0.0005	0.1	0	0.0002		-
Mildew-Proofing & additives	259	0.28	2.2	0.62	3.1	0.002	0.3	-	0.02
Paper & Pulp Manufacture	-	-	-	-	-	-	-		-
Pharmaceuticals	23	-	0.02	-	0.1	-	0/0025	-	-
Amalgamation	-	-	-						
Other	93	21	39	33	93	0.14	5.0		0.6
Subtotal (% of total for media)	2,202	45.5(7%)	399 (29%)	37.6(22%)	482.6(22%)				
Consumption									
Agricultural Pesticides	25	2	13	10	25	0.01	1.5		0.2
Non-Agricultural Pesticides	11	1		4	11	0.007	0.75		0.07
Electrical Apparatus Batteries	659	52	607	-	659	0.35	76		4.2
Lamps	51	6	45	-	51	0.04	5.5		0.3
Paint	256	156	8	1	165	1.04	1.0		1.04
General Laboratory Use	18	2	1	5	8	0.01	0.0125		0.05
Dental Applications	82	-	-	24	24	-	-		-.15
Catalysts	49	0.2	48.8	-	49	0.001	6.1		0.3
Pharmaceuticals	23	1.8	1.2	20	23	0.01	0.15		0.15
Industrial Controls & Instruments	233	5	100	-	105	0.03	12.5		0.07
Subtotal (% of total for media)	1,407(63%)	226(37%)	830(60%)	64(67%)	1,120(52%)				
TOTAL		619.5	1,376.6	172.6	2,169(62%)				
Natural (degassing & runoff)		1,121	-	208	1,229(38%)				
		1,740.5	1,376.6	380.6	3,498				

Table 8
Footnotes

[a]Based upon the same percent lost in 1973 as given in Reference 30.

[b]These data are from the Dept. of the Interior, Bureau of Mines, Reference 45.

[c]The amount produced in 1974. Reference 45.

[d]Normalized losses with utilities as 1.

[e]Based upon the projected annual growth rate of the industry as stated in Reference 30.

[f]These quantities represent the approximate amounts of mercury that remain in the consumer use area after manufacturing losses.

[g]From Table 7.

[h]These sources include livestock, residential fuel oil, refinery, coke ovens, etc., but excludes utilities. The mercury losses are assumed to be those as in reference 30 but with a 5 percent growth rate assumed for 1974.

[i]The total mercury consumed by the industrial instrument industry for 1974 was 236 tons. The division of 81 percent to control instruments and 19 percent to relays & switches are assumed to be the same as in 1973 as in reference 30.

[k]Waste treatment streams and incineration are final disposal methods. The mercury found in waste treatment streams most probably includes the amount dumped by industrial operations as well as consumers. The amount estimated to be emitted from incineration may also include those items containing mercury, discarded by industry and consumer alike, which appear under other categories as losses to land. It is assumed that 8 percent of all solid waste is incinerated.

[l]The percentage of mercury remaining in the consumption sector after manufacturing and processing.

According to present technology it was estimated that about 8 percent of the mercury is lost to the land as a result of dust and tailings from the kiln during processing.[30] Losses from mining of the ores are insignificant.

Copper smelting is a larger source of mercury than mercury smelting. An estimated 105 tons of mercury was released from the processing of over 223,000 tons of ore in 1973. Even though copper production is highly variable we have assumed that the 1974 mercury losses from this source remained the same as was reported for 1973. While the average mercury content in copper ore is 0.5 ppm, the concentration range in ore has been found to be 0.1 to 40 ppm.[47] Mercury losses from the copper smelting source were primarily to the air (55 percent) and land (42 percent). The losses to air were a result of emissions from the furnace stack gas and the off gas from the reactor, which converts SO_2 to sulfuric acid. The emissions to land were from the tailings following ore concentration.

From 1973 figures, more than 83 percent of the smelter production originated in the Mountain States region, with the Pacific region (Washington) and West South Central regions each contributing about 6 percent and the East North Central region (Michigan) contributing 4 percent.

Other mining operations such as zinc and lead mining and smelting as well as cement and lime processing, accounted for 12 percent of the losses from the mining and smelting industry. The industry as a whole accounted for approximately 6 percent of all man-made mercury loses, but 11 percent of all man-made losses to the air.

Unregulated Sources--

The sources grouped here include: utilities; residential, commercial, and industrial use of fossil fuels; refineries; tar and asphalt; coke ovens; livestock; waste treatment, and incineration. The utilities' use of fossil fuel with subsequent mercury losses to the environment have been discussed previously in this report.

Wastewater treatment and incineration are final disposal methods. The estimated mercury losses from these sources are shown to place these final disposal sources in perspective with the producing sources. The mercury found in wastewater treatment facilities comes from the mercury-containing wastes disposed of by other industries. The mercury emissions from the wastewater treatment process amounted to an estimated 130 tons in 1974 based upon an estimated 10% growth in sewer discharges since 1968. It was also assumed that the national average mercury concentration was 2.0 ppb.[30] The mercury from the wastewater treatment process was emitted to the air (26 tons, or 20 percent), land (39 tons or 30 percent), and water (65 tons or 50 percent) as a result of vaporization, incineration, land disposal and water discharge.[30]

The mercury emissions from wastewater treatment would be primarily in urban, industrial high density areas where the large treatment facilities are needed and built. It was estimated that approximately two-thirds of the

wastewater treatment capacity was east of the Mississippi River, with more than half of that concentrated in the northeast quandrant of the United States.

All the remaining "Unregulated Sources" accounted for about one fourth (104 tons) of this source category (Table 8). These mercury emissions are to air (60 percent) and land (42 percent) with the water receiving virtually no direct emission. There is no apparent geographic concentration of these sources, but rather are scattered throughout the country.

All "Unregulated Sources," including the wastewater treatment contribution, accounted for 20 percent of the total man-made mercury losses. Their predominant contribution was to air, accounting for 45 percent of all man-made mercury emissions to that media.

Manufacturing and Processing--

This source category used 2,202 tons of mercury according to 1974 figures,[34] while losing approximately 22 percent of it to the environment. The mercury consumed included that which was U.S. mined and produced, reclaimed (secondary) and imported. As a group this category accounted for 22 percent (483 tons) of all man-made losses to the environment but 22 percent of all the man-made mercury lost to water, 29 percent to the land, and 7 percent to the air. More than 77 percent (374 tons) of this category's total losses originated with one industry, chlor-alkali manufacturing. Another 18 percent was lost from other sources.

The chlor-alkali industry used the second largest amount of mercury of any manufacturing/processing industry, 642 tons in 1974. Of this amount, 58 percent (374 tons) was lost in the various operations of the electrolytic mercury cell process. Most of this loss, an estimated 349 tons, was disposed of to the land. There were 29 chlorine plants, using the mercury cell, located in various parts of the country with almost 75 percent of all mercury emissions occuring from plants in the Southern states, which consist of the South Atlantic, E. South Central, and W. South Central regions.[29] The total emissions to all media in this geographical area, approximately evenly divided among the three regions, was estimated at 212 tons which is about one third of all the mercury consumed by the industry in 1974. The plants located in the states of New York and New Jersey alone accounted for 14 percent, or 41 tons, of the total estimated mercury loss to the environment. Most of the emissions in this industry, about 90 percent, were to land. These estimates were based upon an estimated 3 percent growth in production between 1973 and 1974 which was applied to the losses to the environment as tabulated for 1973.[30,38]

The 93 tons of mercury emitted by the sources classified as "other" was distributed to all media with approximately 40 percent going to land, 35 percent to water, and 23 percent to the air. Geographic distribution was not identifiable from present data. The "Other" category, as described by URS, consisted of many small, diverse uses, often by small manufacturers or processors. Since these would have been difficult to trace, and since

the use appeared to be diverse and widespread, no attempt was made to refine this category.

Consumption--

It was estimated that approximately 63 percent (1400 tons) of the mercury consumed in 1974 by manufacturing and processing was passed on in products for consumption. About 1120 tons of this mercury was lost to the environment, which represented more than half of all man-made losses of mercury to the environment. The remaining 20 percent either remained with the product or was recycled. The largest proportion of this, an estimated 830 tons, was lost to land. This represented 60 percent of all mercury losses to land for all categories. The largest single contributor to this loss was the electrical apparatus industry, which accounted for 652 tons or 79 percent of the land losses from consumption. This large loss, which represented 87 percent of the mercury used by that industry, was due to the discarding of batteries and lamps after use in landfills. The second largest source of mercury to land was from industrial controls and instrument manufacturing, which, as a result of discarded products lost 100 tons in 1974. This represented 43 percent of the mercury used in that industry's end products, and 95 percent of the total lost for that industry. The only other major source of mercury to the land was from the use of catalysts where 99 percent of the mercury used in its manufacture was lost to land after use.

The next largest loss, resulting from consumption of mercury containing products, was to air. This accounted for 226 tons or 37 percent of all man-made mercury losses to the air in 1974. The largest source, accounting for 69 percent of these losses (156 tons) was from paint. Its use in such products as latex paint has wide application. There were 256 tons of mercury available in paints in 1974 of which 61 percent (156 tons) was lost to the air through vaporization. Another 36 percent remained bonded to the painted surface. The second largest, and only other, major source of mercury to air in this category was from electrical apparatus consumption. The 58 tons lost to the air were the result of discarded batteries and lamps entering incinerators, and during which process mercury was vaporized.

The smallest loss of mercury, which resulted from product consumption, was the loss to water, which accounted for 6 percent (64 tons) of this category's losses but 37 percent of all man-made mercury losses to water. Dental applications and pharmaceuticals accounted for 70 percent of the 64 tons of mercury involved (24 and 20 tons respectively), followed by agricultural pesticides (10 tons). These mercury losses resulted from products being flushed into sewers or contained in runoff.

General--

Of the approximately 2169 tons of mercury lost from man-made sources in 1974, the consumption category accounted for more than half, followed by manufacturing and processing (22 percent), unregulated sources (20 percent) and mining and smelting (6 percent). There were, however, natural sources of mercury which were estimated at 1329 tons, or 61 percent of the amount

released to the environment in 1974 from all man-made sources.[30] This natural mercury was emitted to the air through the mechanisms of degassing and runoff. These machanisms will be discussed later in the report. The source is a combination of the natural mercury found in the earth's crust and mercury which was lost to land or water becoming volatilized. This source, while uncontrollable, was the largest single source of mercury to the environment, representing 38 percent of all mercury lost to the environment.

When comparing the mercury lost from natural and man-made sources, it was estimated that natural sources lost about 1.8 times the amount of mercury to land and 1.2 times the amount to water that all man-made sources lost to each of these media. The distribution of mercury lost from man-made and natural sources to the environment, on a regional basis, is shown in Table 9.

Comparison of Power Plant Emissions with Emissions From Other Sources

The previous section dealt with the magnitude of the various sources of mercury in absolute terms. In order to assess the emissions from power plants it is necessary to examine the relative magnitude of this source with respect to the other sources on both a national and regional basis. Table 8 presents the mercury losses to the environment from power plants relative to the other sources. In this comparison, the mercury losses from utilities were considered one with the others normalized to that base.

Examining total losses from all man-made mercury sources in 1974, (Table 8) utilities ranked fourth (<8 percent of total man-made mercury emissions), on a nationwide basis, after Electrical Apparatus-Battery Consumption (33 percent of total), Chlor-Alkali Manufacturing (17 percent), and Paint-Consumption (8 percent). Wastewater treatment as a source ranks behind utilities with about 6 percent of the total mercury lost. Following close behind utilities, each representing 5 percent of the mercury losses, were Copper Smelting, Other Unregulated Sources, and the Consumption of Industrial Controls and Instruments. If natural sources are considered, then they would rank out in front having mercury losses to the environment of the order of magnitude of almost 8 times those of utilities. Utilities, as a source, would then be moved down to fifth place in relative losses of mercury. In comparison, utilities ranked fifth in 1973 with about 4 percent of total mercury lost.[30]

The relative amount of mercury lost by utilities to the atmosphere compared to the other sources, again on a nationwide basis, was different than when compared on a total basis. Only one other source exceeded it, and that was the loss from paint consumption due to vaporization. The relative loss between the two sources is 1.04:1, with 156 and 150 tons respectively. The next closest sources are Copper Smelting and Other Unregulated Sources with 58 and 60 tons respectively, followed by Electrical Apparatus Consumption (Batteries) at approximately one-third the utility emissions, and incineration at <0.3 that of utilities.

TABLE 9. REGIONAL DISTRIBUTION OF MERCURY LOSSES IN THE UNITED STATES IN 1973[a]

(tons)

Region[b]	From Man-Made Sources to			From Natural Sources to		From Wastewater Treatment	Total (tons)
	Air	Land	Water	Air	Water		
New England	26.3	54.3	5.4	18.1	1.0	2.8	107.9
Middle Atlantic	93.4	183.2	17.2	40.2	1.8	9.8	345.6
East North Central	96.0	182.5	19.1	49.6	8.8	10.4	366.4
West North Central	38.0	76.0	9.0	95.1	22.8	4.0	244.9
South Atlantic	68.5	173.1	13.3	93.1	8.5	7.0	363.5
East South Central	39.1	120.7	6.6	37.2	19.3	3.0	225.9
West South Central	46.1	135.5	9.0	89.0	52.0	5.6	337.2
Mountain	56.8	34.3	6.0	448.9	63.9	2.2	612.1
Pacific	50.3	96.4	10.0	157.8	30.0	6.5	351.0
TOTALS	514.5	1056	95.6	1029	208.1	51.3	2954.5

[a]Reference 30

[b]The regions are the same as in Table 5

Mercury losses directly to the water are considered to be zero for utilities. Mercury from power plant emissions contribute to the ambient mercury concentration of water, but primarily as a result of transfer mechanisms from other media as will be discussed in Section 7. Fifteen of the other sources contributed mercury to water, ranging from 0.2 tons from catalyst production to 65 tons from waste treatment.

The loss of mercury to land by utilities occurs when ashes containing mercury are disposed of in a landfill. To be conservative it is assumed that 10 percent of the mercury in coal is ultimately found in the ash, while all the mercury in oil enters the stack gas.[22-25] Based upon utility consumption of fossil fuels, utilities ranked ninth among the sources, along with paint consumption. The most pronounced differences were with the chlor-alkali industry, with 43.5 times the mercury losses to land and with the consumption of electrical apparatus - batteries and lamps - with combined losses of mercury to land of 81.5 times those of utilities (76 and 5.5 times respectively), or 652 tons. These were followed by the consumption of industrial controls and instruments at 12.5 times the amount of mercury. In addition, if wastewater treatment is considered an independent source, it would rank ahead of utilities with 4.9 times the amount of mercury lost to land.

A relative ranking, considering the losses from natural sources, such as degassing, would place utilities third. Degassing contributed 7.5 times more mercury to the air than utilities. However, more than half the mercury lost to the air from degassing occurred in the Mountain and Pacific regions.

One method of assessing the contribution of utility losses to total man-made mercury losses is to examine the ratio of the two on a regional basis as well as the trend from region to region. Figure 1 is a graphical representation of the relationship between utility and total man-made losses of mercury to the air, on a regional basis.

The largest contribution by power plants to all mercury emissions to the environment was 12.3 percent in the South Atlantic region. The power plants in this region accounted for 20 percent of the net electrical generation in the United States in 1974, with 93 percent of the Btu as a result of the combustion of coal and oil. The lowest proportional contribution occurred in the West South Central region where power plants contributed 1.9 percent of all mercury emissions. Power plants in this region produced 15 percent of the total net electricity generated in the United States. However, only 9 percent of the Btu's produced in generating the power were from the combustion of coal and oil.

The contribution of power plants on a percentage basis to mercury emissions to the air, as compared with total mercury emissions, was considerably greater. The power plants contributed an estimated 47 percent of all air emissions in the South Atlantic region. While this represented the highest estimated amount of mercury emitted to the air from power plants in a region, the highest regional emissions to air from all sources occurred in the Middle Atlantic and East North Central regions (107 and 110 tons respectively). In these regions, the contributions to the air from power plants

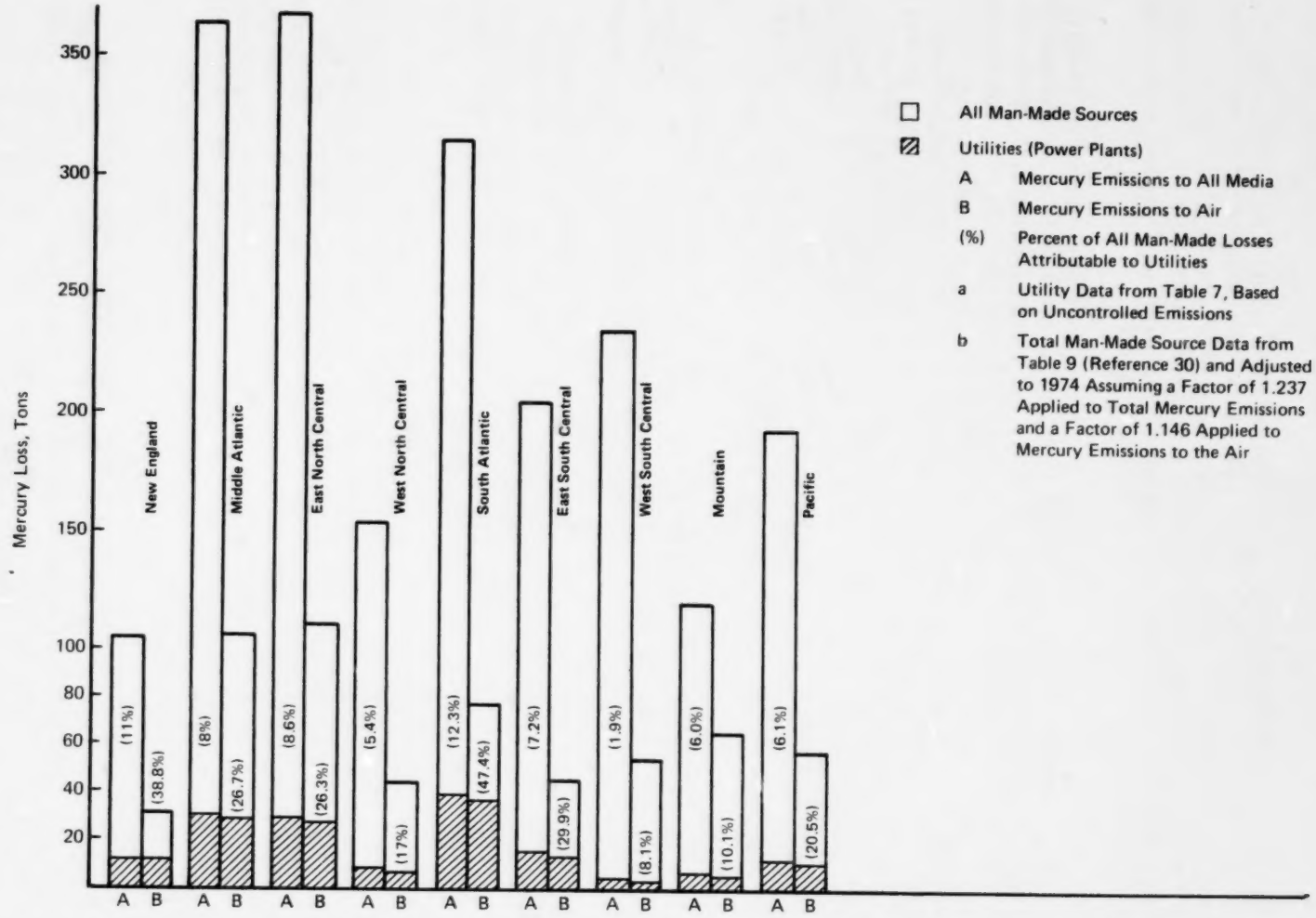

Figure 1. Comparison of mercury losses between utilities and all man-made sources, by region (1974)[a,b]

were each about 26 percent while together providing about one-third of the net power generated in the United States (12.4 and 21.3 percent respectively). The lowest contributions were in the West South Central and Mountain regions (8.1 and 10.1 percent). The West South Central region accounted for about 25 percent of the mercury lost from the chlor-alkali industry, while the Mountain region accounted for much of the smelting.

The regional data for all man-made sources was available for 1973.[30] Total man-made mercury emissions to the environment for 1974 indicated an increase of 23.7 percent over the 1973 data. As a basis for comparing 1974 power plant emission data from this report to regional data from all man-made sources, a factor of 1.237 was applied to the 1973 regional data found in the literature. Similarly for emissions to air, a factor of 1.146 was applied regionally. The accuracy of some of the 1973 data used may be questionable, especially in regard to power plant emissions which were included in the all-sources data. The power plant emission data used in this report are 2.5 greater than those in the URS Research Company report. The larger values were used as they were based upon power plant operating data for 1974, which included fuel mix, as well as the average mercury content of the fuels.[19,30] However, these data are still useful in assessing the relative importance of power plant emissions. While they may have accounted for almost half of the mercury emissions to the air in a particular region, they were a relatively small contributor to the mercury emitted to the environment. They may, in fact, have been smaller yet as a result of some mercury removal which may have occurred in the use of required emission control equipment by power plants. The data for other sources appear to have included any emission controls normally associated with a particular industry's operations.

MERCURY EMISSION CONTROL AND PROJECTIONS

There is presently no mercury emission control technology used by utilities. There are industries which, through recycling and good "housekeeping" practices, are able to limit mercury losses. This section will briefly review current power plant control systems as well as those used by industries considered to be sources of mercury to the environment. Mercury emissions are projected to 1983 based upon future consumption and controls. The relative importance of power plant mercury emissions is examined with respect to the projections.

Technology of Power Plant Control Systems

At present the three devices most often used for control of pollutants from power plants are electrostatic precipitators, baghouses, and scrubbers. Brief descriptions of each device follow with an estimate of their effectiveness in reducing mercury emissions.

Electrostatic Precipitators--

Electrostatic precipitators (ESP) are efficient devices for the removal of particulates from gas streams. Particulate removal efficiencies of over 99 percent are common in properly maintained utility applications. The process involves three basic steps: charge, transport, and particulate

collection. An ionizing effect is created by means of a very high voltage discharge through a wire parallel to and between two collection plates. This applied discharge impresses on the particulate matter a charge opposite to that of the collection plates. The opposite charge on the particulates will cause the transport of these particulates, in the stack gas, to the oppositely charged plates. The third step removes the particulate from the collection plate, by rapping the plates, using mechanical hammers, causing the collected particulate to fall to the hopper below.

A number of factors influence the collection efficiency of the ESP, including particle size, gas stream velocity, particulate resistivity, and corona strength. Since mercury is usually in the vapor form at normal stack temperatures (300°F) it would be expected that little if any mercury will be collected by an ESP. Limited testing on power plants equipped with ESP has substantiated this assumption.[32,35,48] Samples generally were collected in the breaching on the outlet side of the electrostatic precipitator, in addition to various other locations from the fly ash hoppers to the stack. The limited sampling indicated the loss of mercury primarily as a vapor, thus escaping capture by the ESP. There were few data points collected, and in some cases the testing program was incomplete. Analytical methods also varied. When material balances were done around a power plant imbalances were found, which ranged as high as 85 percent. One way to promote mercury collection by an ESP would be to lower the flue gas temperature causing condensation of the vapor and subsequent adsorption onto the particulate, which in turn would be collected. Current heat recovery equipment is not suitable for lowering the flue gas temperature much beyond what it now does, and diluting the flue gas with ambient air is probably uneconomical since the cost of an ESP depends upon the volume of flue gas treated. In addition, reduction of stack gas temperature can create problems in releasing the stack gas to the atmosphere. A reduced temperature differential slows both the effective rate and the height of the discharge causing dispersal at a significantly lower altitude. To obviate the problem the gas would have to be reheated prior to exiting the stack, an expensive operation. In summary, therefore, it is not anticipated that electrostatic precipitation can play a role in controlling mercury emissions from power plants.

Scrubbers--

Scrubbers, are used in power plants for the control of particulates and/or gaseous pollutants. Particulate scrubbers are generally a cyclone design of a wet or dry type. The basic operating principle is the inertial separation of particulates from a gas stream. The stack gas enters the cyclone tangentially causing the particulate matter to be pulled to the walls of the cone while spiralling downward. A hopper beneath the cyclone collects the falling particulates allowing the cleaned (scrubbed) gas to exit upward through the exhaust port in the center of the scrubber body. Efficiency may be increased by means of a water spray which causes particle agglomeration and promotes the scrubbing action.

Gaseous pollutants are scrubbed using a material, usually a liquid, which either through adsorption or reaction selectively removes the undesirable component(s). The operating mechanism is diffusion of the pollutant to the

scrubbing medium upon contact. The principle gaseous component for which scrubbers are used is sulfur dioxide. There are a number of SO_2 scrubber systems in use and under study. A description of these systems is beyond the scope of this document.

Mercury emissions may be expected to be reduced by the action of scrubbers. Investigations into the effect of scrubbers on mercury emissions are not known to have been conducted. Some limited data were available from a scrubber study which included spot analyses of a number of substances including mercury.[32,48] The data indicated that mercury emissions may be reduced by up to a third when the flue gas was scrubbed for SO_2.

Baghouses--

Fabric filtration is an efficient means for removing particulate from gas streams. High efficiencies, even for sub-micron particulates, have been obtained. The principal mechanism of collection is impaction. The fabric traps the larger particulates, closing the open mesh area substantially. The cake which builds up is able to stop smaller and smaller particles from getting through with the passing stack gas. The pressure drop increases with the buildup until bag cleaning is required. Baghouses must withstand a variety of operating temperatures depending upon application. A variety of fabrics are available to cope with these temperature ranges.

The temperatures at which most baghouses are maintained are sufficient to prevent condensation. Some mercury may, however, be adsorbed or chemically react with the filter cake effectively reducing emissions. The only data available are from a study which investigated the fate of mercury in the combustion of coal in a bench type unit.[34] In this study 55 to 60 percent of the mercury in the coal was found on particulate collected by the baghouse (operated above 300°F) while only 31 to 36 percent was found in particulate from a larger unit which used mechanical collectors. It is reasonable to assume that adsorption may have been a primary mechanism in mercury collection. Without further study, however, it is impossible to extend these results to field units because of the differences in temperature, mercury concentration, and physical/chemical fly ash characteristics.

Technology of Control Systems for Other Industries

The control techniques used in sources other than power plants are often similar. Under normal circumstances particulate control systems are either ESP, cyclone, or baghouse. Depending upon a number of parameters, their ability to remove mercury from the gas stream will probably vary considerably. A lack of comprehensive data precludes rendering any judgments in this regard.

Where substantial quantities of sulfur dioxide are present and must be scrubbed from the gas stream as mandated by law, special control systems are used. These are basically process units whose output or end product is commercially usable sulfuric acid or elemental sulfur. As with other systems, there is little known about their effect on controlling mercury emissions.

Current systems for the control of mercury emissions for various sources other than power plants will be reviewed in this section.

Liquid effluents and sludges are handled either through waste treatment techniques or landfilling. The former may cause mercury to be captured in a sludge. These sludges are either burned or placed in a landfill. Neither controls the mercury, but merely transfers it to a different medium for release to the environment. These methods will not be discussed here.

Mining and Smelting--

Current mercury recovery plants extract ore, crush it, and feed it to a rotary kiln. The dust from crushing is uncontrolled. There is little mercury at this point, because there are only 5 lbs. of mercury for each ton of ore. The effluent gases from the kiln are passed through a scrubber (cyclone) to collect dust. The mercury passes, as a vapor, to a condenser where the mercury is removed. Industrial losses occur at this point with the effluent gases passing directly through the stack.

The copper smelting process uses both cyclones and electrostatic precipitators on the exhaust of the reverberatory furnace. These have little effect on capturing mercury according to one industry flow diagram.[22] The converter exhaust, however, passes through a reactor for producing sulfuric acid. Indications are that two-thirds of the mercury in the exhaust will remain in the sulfuric acid.

Chlor-Alkali Manufacturing--

The mercury cell process emits mercury with hydrogen during the decomposing of sodium amalgam formed in the cell. Cooling to 55°C from 80°C is effective in retaining 98 percent of the mercury, the remainder being emitted during the flowing of the hydrogen.

Mercurials--

Most losses involve liquid wastes or applications to land, neither of which control the emission.

Electrical Apparatus--

The production of batteries accounts for small losses. Recycling is used in the manufacture of Ruben mercury batteries, thus controlling mercury losses. Losses which do occur are uncontrolled and involve discarding the product. The manufacturing of fluorescent lamps has no controls. Losses are from broken and discarded products.

Industrial Instruments and Controls--

Manufacturing losses are small, with no special control systems. Major losses occur as a result of discarding products.

Paint Manufacturing--

There are no special control systems used. One major problem arises as a result of small manufacturers who flush wastes down the sewer, rather than treating it or disposing of it properly.

Projected Mercury Emissions and Controls

A projection of mercury losses to the environment in 1983 was made to coincide with EPA emission standards which have been established for that year. The data are based upon a technological assessment of mercury and its compounds conducted by URS Research Company.[30] The data are shown in Table 10. The URS report as mentioned, was used because of its comprehensive data. The data in the 1983 projection had been arrived at through a number of assumptions for each industry in terms of product demand, population growth, process efficiencies, control technologies, and regulatory requirements. The bases for these projections will be briefly discussed as will the relative importance of projected power plant emissions to the other sources.

A number of conclusions can be drawn from the projections as shown in Table 10 when compared with the 1974 figures in Table 8. On an overall basis, the total mercury loss for all sources projected for 1983 are about 2 percent lower than for 1974. The mercury loss to air is projected to increase 26 percent as a result of an anticipated increase in power plant emissions. Emissions to both land and water are expected to decrease in 1983 by 13 percent and 12 percent respectively. Both the "Unregulated Sources", and "Consumption" are estimated to show an overall increase by 1983 of 32 percent and 18 percent respectively, while "Mining and Smelting" and "Manufacturing and Processing" will decrease by 53 percent and 64 percent respectively.

The ranking of mercury losses to the environment by sources and by media for 1974 and 1983, is shown in Table 11. A relative ranking of sources, based upon the 1983 projections, would place utilities first in mercury losses to the air with an estimated 230 tons (30 percent of all losses to air). Other major ranked sources of mercury to the air include Paint Consumption with 191 tons (25 percent), Battery Consumption with 119 tons (15 percent), and Other Unregulated Sources with 92 tons (12 percent). This compares with a ranking of second for Utilities in 1974 with 24 percent of all losses to air, behind Paint Consumption which ranked first with 25 percent. Utilities are estimated to rank seventh in mercury losses to land with 25 tons (2 percent of losses to land). This compares to the 8 tons lost to land in 1974 (0.6 percent of land losses). Consumption of Electrical Apparatus-Batteries are projected to rank first with an estimated 691 tons (58 percent). Utilities are not considered to lose mercury directly to water. Many of the bases of the projected losses are 1973 consumption and emissions figures.

- Mercury production may increase in this country 10-50 fold over 1973 production. Emissions from new plants, however should be reduced as a result of an increase in process efficiency and control technology.

- Projections for copper mining and smelting emissions are based upon the increased concern by and regulation of the industry to clean up major pollutants. The economic feasibility of mercury recovery may result in approximately 85 percent of the mercury now lost by copper mining and smelting operations being recovered.

TABLE 10. PROJECTED MERCURY LOSSES TO THE ENVIRONMENT, 1983[a]

SOURCE	MERCURY LOSSES (TONS)				LOSSES RELATIVE TO POWER PLANT LOSSES (RANK)			
	AIR	LAND	WATER	TOTAL	AIR	LAND	WATER	TOTAL
Mining and Smelting								
Mercury	23[b]	-	-	23[b]	0.1	0		0.1
Copper	3	9	0.2	12.2	<0.1	0.4		<0.1
Other	18[c]	5[c]	1.4[c]	24.4[c]	0.1	0.2		0.1
Subtotal (% of Total for Media)	44(6%)	14(1%)	1.6(1%)	59.6 (3%)				
Unregulated Sources								
Utilities	230[b]	25[b]	-	255[b]	1	1 (5)	-	1
Other	92[c]	67[c]	4[c]	163[c]	0.4	2.7 (3)		0.6
Waste Treatment[d]	20	36	59	115	0.1	1.4 (6)		0.5
Incineration[d]	23	23	-		0.1	0.9 (8)		0.2
Subtotal (% of Total for Media)	365(47%)	151(13%)	63(41%)	580 (27%)				
Manufacturing and Processing								
Catalysts	0.02	8	0.03	8.1	<<0.1	0.3		<0.1
Electrical Apparatus - Batteries	0.2	4	0.1	4.3	<<0.1	0.2		<0.1
Lamps	0.2	3	-	3.2	<<0.1	0.1		<0.1
Chlor-Alkali	14	53	0.1	67.1	<0.1	2.1		0.3
Industrial Controls and Instruments	0.2	4	-	4.2	<<0.1	0.2		<0.1
Mercurial Mfg.	0.01	0.02	0.5	0.5	<<0.1	<<0.1		<<0.1
Paint Mfg.	0.3	3	0.1	3.4	<<0.1	0.1		<0.1
Other Mfg.	18	35	30	83	0.1	1.4		0.3
Subtotal (% of Total for Media)	32.93(4%)	110(9%)	30.8(20%)	173.8 (8%)				
Consumption								
Agricultural Pesticides	-	9	2	11	0	0.4		<0.1
Non-Agricultural Pesticides	5	24	19	48	<0.1	1.0		0.2
Electrical Apparatus - Batteries	119[b]	691[b]	-	810[b]	0.5	27.6		3.2
Lamps	9	56	-	65	< 0.1	2.2		0.3
Industrial Controls and Instruments	11	127	-	138	< 0.1	5.0		0.5
Paint	191	9	1	201	0.8	0.4		0.8
General Laboratory Use	1	1	2	4	<<0.1	< 0.1		<0.1
Dental Applications	-	-	13	13	0	0		<0.1
Pharmaceuticals	1	2	20	23	<<0.1	< 0.1		0.1
Catalysts								
Other	0.2[c]	4[c]	-	4.2[c]	<<0.1	0.2		<0.1
Subtotal (% of Total for Media)	337(43%)	923(77%)	57(38%)	1317.2 (62%)				
Total[d]	779	1198	152	2131				

a Reference 30
b The highest estimate when a high-low estimate was made.
c Estimated at 5% increase per year, with emission controls limited to present technology.
d These figures do not represent a material balance.

TABLE 11. MERCURY LOSSES TO THE ENVIRONMENT - RANKED BY SOURCE [a,b]

RANK	MERCURY LOSSES (TONS), 1974								MERCURY LOSSES (TONS), 1983							
	AIR		LAND		WATER		TOTAL		AIR		LAND		WATER		TOTAL	
1	Paint Consump.	(156)	Battery Consump.	(607)	Waste Treatment	(65)	Battery Consump.	(659)	Utilities	(230)	Battery Consumption	(691)	Waste Treatment	(59)	Battery Consump.	(810)
2	Utilities	(150)	Chlor-Alkal Mfg.	(349)	Other Mfg.	(33)	Chlor-Alkali Mfg.	(374)	Paint Consump.	(191)	Ind. Cont & Inst. Use	(127)	Other Mfg.	(30)	Utilities	(255)
3	Other Unreg.	(60)	Indust. Cont. Consump.	(160)	Dental Applic.	(24)	Paint Consump.	(165)	Battery Consump.	(119)	Other Unreg.	(67)	Pharmaceutical Consump.	(20)	Paint Consump.	(201)
4	Copper Smelt.	(58)	Catalyst Consump.	(49)	Pharm. Consump.	(20)	Utilities	(158)	Other Unreg.	(92)	Lamp Consump.	(56)	Non-Agric. Pest.	(19)	Other Unreg.	(163)
5	Battery Consump.	(52)	Lamp Consump.	(45)	Agric. Pesticides	(10)	Waste Treatment	(130)	Incineration Mercury Smelt.	(23) (23)	Chlor-Alkali Mfg.	(53)	Dental Applic.	(13)	Indus. Cont. & Inst.Use	(138)
6	Incineration	(41)	Copper Smelting Other Unreg.	(44) (42)	Gen'l Lab Use	(5)	Copper Smelting Industrial Cont & Instl. Use	(105)	Waste Treatment	(20)	Waste Treatment Other Mfg.	(36) (35)	Other Unreg.	(4)	Waste Treatment	(115)
7	Waste Treatment	(26)	Other Mfg.	(39)	Non-Agric. Pest.	(4)	Other Unreg.	(104)	Other Mining Other Mfg.	(18) (18)	Utilities Non-Agric. Pest.	(25) (24)	Agric. Pest. Gen'l. Lab Use	(2)	Other Mfg.	(83)
8	Chlor-Alkali	(22)	Waste Treatment Agric. Pest.	(39) (13)	Chlor-Alkali Mfg. Copper Smelting	(c)	Other Mfg.	(93)	Chlor-Alkal Mfg.	(14)	Incineration	(23)	Other Mining & Smelt	(1.4)	Chlor-Alkal Mfg.	(67)
9	Other Mfg.	(21)	Paint Consump Utilities	(8)	Other Unreg.	(2)	Lamp Consump.	(51)	Ind. Cont.& Inst. Use	(11)	Copper Smelting Agric. Pest. Paint Consumption	(9)	Paint Consump.	(1)	Lamp Consump.	(65)
10	Other Mining & Smelting	(11) (2)	Mercury Smelting	(7) (6)	Paint Consump. Other Mining & Smelting	(1)	Catalysts Consump.	(49)	Lamp Consump.	(9)	Catalysts Mfg.	(8)	Mercurial Mfg.	(0.5)	Non-Agric. Pest. Incineration	(48) (47)

[a] Utility losses are based upon uncontrolled emissions

[b] From Tables 8 and 10

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• Power plants are expected to increase net power generation by an estimated 63 percent to 2.3 x 10^{12}kwh in 1983.[18] Utility use of fossil fuel is projected to increase in 1983 by 73 percent for coal and 49 percent for oil.[49] The increased use of coal in place of oil will reduce the mercury emissions to air per kilowatt hour of electricity generated. Based upon fuel rates and average mercury concentrations in both coal and oil, the use of coal produces about one-third of the mercury than does oil per kilowatt hour of electricity generated. A shift in geographic coal mining patterns to the Northern Great Plains is expected by the mid-1980's.[18] The concentration of mercury in this coal is about one-third that of Appalachian coal. It is expected to go from its present 8 percent (52 million tons) of the coal produced to almost 30 percent (305 million tons) in 1985.[18]

As was discussed, the mercury contribution from gas was not considered. It is considered that the consumption of gas by utilities as a fuel to generate electricity will decrease about 42 percent. If one would assume no mercury removal prior to the transmission of the gas, it would yield an estimated 2.9 tons to the air (1 percent of the utility losses). It is assumed from current utility schedules that approximately 14 percent of the net power generated will be under SO_2 scrubbers by 1983.[50] The estimated mercury loss to the air is based upon this assumption together with an assumed 33 percent mercury scrubbing efficiency. The projected power plant emissions used in Table 10 are almost three times larger than the URS study report data. These larger values were used because they were based upon the above factors which appeared to be the best available projections of electric industry growth, and fuel production, as well as known scrubber committments for utilities.

• It is assumed that the chlor-alkali industry will not expand mercury cell chlorine production, thus decreasing mercury loss to the environment by 82 percent by 1983. This reduction will be due to the new source performance standard (NSPS), currently in progress (1977) at EPA, for chlor-alkali plants which would establish a zero emission limit for new plants. This would essentially force all new plants to use asbestos diaphragm or membrane cells. Reductions will also result from plant compliance with existing regulations and improved housekeeping procedures relating to mercury accountability. Emissions to the air should be reduced by 36 percent through increased control of the hydrogen stack emission and tighter internal controls. Water losses will be substantially reduced by compliance with regulations and through best available treatement standards limiting discharges to 0.05kg/day. Land losses will be greatly reduced by techniques which are currently in development to recover mercury in sludges.

• Production of mercurials is expected to remain steady or slightly decrease in the future due primarily to the hazardous nature of the compounds and declining demand among end users. Discharge from production will decrease by the development of methods to remove trace quantities from water effluents. Most of these methods are based upon the precipitation of mercuric sulfide from the effluent stream by injection of sodium sulfide. Molecular sieves,

which will probably be in use by the chlor-alkali industry as a secondary tail-end device, may be used as a primary device in the manufacturing of mercurials.

- Consumption of mercurials in pharmaceuticals by consumers will probably drop from 23 tons in 1973 to 19 tons in 1983, due to the decline in the use of mercury in diuretics and skin preparations. Pharmaceutical industry consumption of mercury in 1974 remained at the same level as in 1973. Relative losses to different media will probably remain at the same level.

- Primary battery production is expected to increase by 45 percent from 1973 to 1983 with no change in the manufacturing process. Due to tight internal controls, manufacturing losses should be reduced to 0.5 percent of the mercury used in production. Losses to landfills should increase by 31 percent if recycling approaches 10 percent (currently 5 percent) and decrease by 27 percent if a 50 percent recycling program is implemented.

- The proportion of electric lamps using mercury is expected to increase approximately 50 percent between 1973 and 1983, but tight controls should limit manufacturing loss to 4 percent of total input. If a 5 percent recycling program is initiated, mercury losses to landfills will increase by only 43 percent.

- The industrial controls and instrument industry is projected to exhibit a 14 percent growth rate for this period. Since recycling is not expected to increase (presently 55 percent) the increase in emissions should also be 14 percent. The URS 1983 projection for this industry may not hold insofar as the average 1974 loss of mercury during manufacturing and consumption (Table 8) was apparently 15 percent lower than their loss data for 1973.[30]

- A 5 percent growth rate in paint manufacturing coupled with a 50 percent reduction in mercury usage would result in the same amount of mercury being emitted to the environment in 1983 as was emitted in 1973.

- An assumption with regard to agricultural pesticide use, is that without further regulation the decrease in use of mercuric pesticides would be about 50 percent by 1983.

- Use and dispersion to the environment of non-agricultural pesticides containing mercury is assumed to be constant, according to URS. When compared with 1974 figures, there may be an increase of 436 percent.

- Mercury losses to the environment from laboratory use should drop by a factor of 50 percent or more as recycling of laboratory mercury increases to 80 percent.

- Municipal waste treatment technology will probably remain unchanged based upon current funding and construction trends. Most plants will provide secondary treatment, with a few providing tertiary treatment. Reductions

in industrial emissions of mercury could have a significant effect on the amount of mercury to be found in waste treatment plants in 1983. Presently, industrial emissions account for about 35 percent of the input.[30] Recycling by institutional mercury users would also reduce mercury emissions. It is also assumed that sludge incinceration will decrease by 50 percent due to air pollution regulations and energy conservation problems.

- While the total amount of solid waste generated is expected to increase substantially by 1983, the amount of mercury-containing wastes is expected to decrease due to greater industrial control and a decline in the use of mercury in some manufacturing sectors. An increase in resource recovery operations and solid waste regulation of hazardous substances is also assumed. A decrease in air emissions is anticipated as a result of the use of tail-end mercury recovery units for thermal conversion processes, whose efficiency is assumed to be 50 percent. These factors will tend to decrease the mercury containing wastes presently incinerated. Decreases in water emissions should result from improved landfill practices.

SECTION 7

TRANSPORT AND FATE OF MERCURY EMISSIONS FROM POWER PLANTS

The mercury which enters the environment, as a result of the various source emissions previously discussed, can be in various chemical forms. These different chemical forms interact within the environmental media (air, water and land) in a complex manner. The fate and transport of mercury in the environment is characterized, as are ambient concentrations. A number of studies are cited which provided ambient concentration data. It is the purpose of this section to examine the mercury emissions from power plants as to their contribution to and effect on ambient mercury concentrations. The significance of these power plant effects was shown through specific studies which have been conducted and through scenarios which were created to illustrate effects under implausible conditions. The purpose of using implausible conditions was to determine if the ambient concentrations would be found to be within standards, under these conditions. If so, then emissions would be considered not to be a problem.

CONCEPTUAL MODEL AND INTERMEDIA TRANSFERS

The presence and the behavior of mercury in the environment may be described by a cycle, as shown in Figure 2, and as proposed by others.[22,39,40] It has been shown that the various sources, anthropogenic and natural, lose mercury to the air, land, and water. These losses to the media may be direct or indirect, and all occur by means of transfer mechanisms or pathways. Mercury is emitted to the air, as a result of volatilization during combustion or other process. Depending upon meteorological parameters and the constituents present in the air, the mercury may undergo transformations which will be discussed and intermedia transfers. The result may be a rapid mercury transfer to land or to water, or it may be a retention in the atmosphere for an indefinite period of time before transfer, or it may be dispersed and remain in the atmosphere. The direct transfer to land may occur through one of three possible paths.

Particulate matter, onto which mercury was adsorbed, when settling out of the atmosphere to impact and interact with the land, is considered dry fallout. Wet fallout refers to washing of mercury out of the air, either through solubilizing the vapor or adsorption onto particulates during precipitation (rain, snow, etc.). The third is solid adsorption at the vapor/land interface. This may result from normal surface contact or plume touchdown. Direct transfer to water may occur via similar mechanisms,

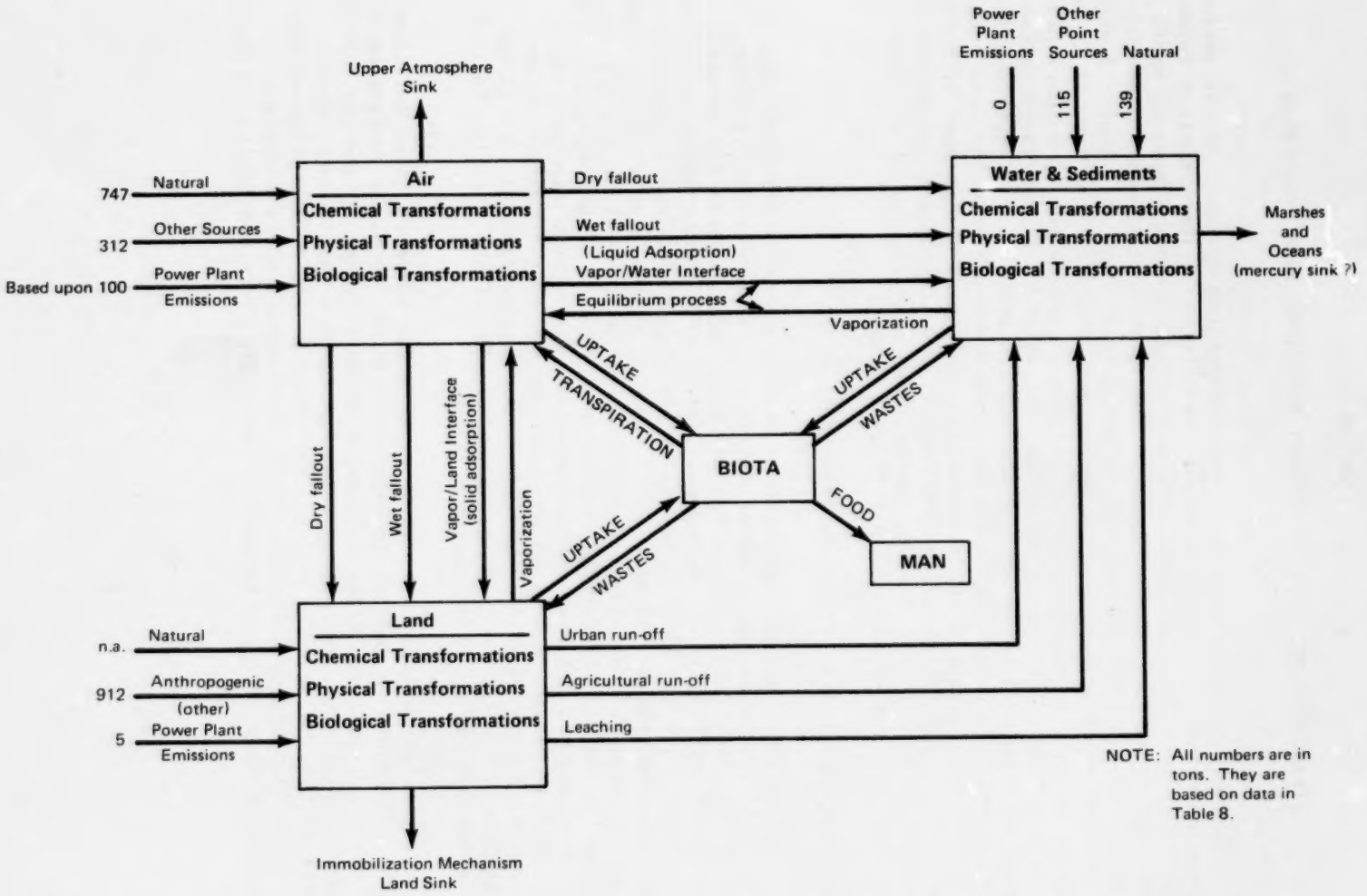


Figure 2. Conceptual cyclic model of mercury transport in the environment.

dry and wet fallout onto surface waters and liquid absorption at the vapor/water interface. An additional transfer may be from air to certain biota through natural uptake such as respiration or ingestion.

Mercury in the soil is the result of disposal of solid waste of various substances containing mercury, contributions from natural deposits, and transfers from the atmosphere and biota. There are several pathways which permit transport of mercury to the air, water, and biota. Volatilization of mercury in soils is the mechanism which transfers mercury from land to air. Runoff in urban areas carries matter on which mercury is adsorbed, or with which it is combined, into surface waters (streams, rivers, lakes), thus transferring mercury from land to water and sediments. Agricultural runoff containing mercury in the form of pesticides, applied either as a spray or on treated seeds, eventually is transferred to water and sediments. Some mercury may be carried downward by percolation, possibly becoming immobilized through chemical combination. Leaching can transport mercury to surface water or ground water. Biota can receive mercury in the uptake of land based nutrition. Similarly, mercury can be returned to land from biota as wastes.

While such a cycle may be conceptualized along with its intermedia mechanisms for transfer, it is not possible, with the data at hand, to measure rates and quantities transferred. It is possible, however, to define ranges for the relative ambient concentrations of mercury in the various media as a result of source emission and subsequent transport phenomena. The significance of mercury emissions from power plants on ambient concentrations may then be evaluated.

SIGNIFICANCE OF POWER PLANT EMISSIONS ON AMBIENT CONCENTRATIONS

The following conclusions, regarding the significance of mercury emissions from power plants and the fate and transport of mercury in the environment, arise from the discussions found in the remainder of Chapter 7:

- Mercury emissions from power plants generally have an insignificant effect on ambient concentrations (air, water, and land). A detectable increase in soil concentrations on a local basis may, however, occur. While mercury concentrations in soil may be significant on an absolute basis, its significance on a relative basis is not known.

- Mercury levels may increase in a closed water system, with no apparent direct man-made inputs, as a result of both accumulation in the sediments and bioamplification.

- As much as 86 percent of the mercury transported by water is in solution, the remainder being on suspended particulate or re-entrained bottom sediments.

- Mercury in solution will ultimately be carried to the oceans as will up to 20 percent carried on particulate. The remainder, carried on particulate, will be deposited in coastal areas.

- Atmospheric input may effect near-shore ocean concentrations. However, what available data there is, is not significant.

Air

Studies of the ambient concentration of mercury in air have been conducted but are not definitive.[30,51-56] In a report assessing mercury in the environment, the range of ambient concentrations of mercury in city air was given as 0.001 ppb-20.0 ppb and in urban air as high as about 30 ppb.[30] City figures represented the downtown area, while urban figures represented the populated area around the city. These values are on a weight to weight basis.

Kothny examined the ambient atmospheric concentration associated with mercury sources and determined that rural areas had a concentration range of 0.0006 - 0.008 ppb.[51] The recommended ambient air concentration, which was the basis for the National Emission Standard for mercury, is 1.0 g/m^3(0.8 ppb). In addition, he determined that the ambient concentration range of indoor air was 0.02 - 0.25 ppb, while industrial and commercial atmosphere was as high as 42 ppb. This is generally lower than the NIOSH recommended workplace exposure of 0.05 mg/m^3(40 ppb). The high values for indoor air were ascribed to the mercury volatilized from latex paint and PVC materials commonly used. Indoor industrial concentrations were associated with chlor-alkali plants, dental offices and various manufacturing sources.

Ambient mercury concentration ranges, during the winter, in the San Francisco area were found to be 0.0004 ppb - 0.02 ppb while those during the summer months were from 0.0008 ppb - 0.04 ppb.[53] A study performed in California measured elemental mercury in the vicinity of natural sources (mines, geothermal vents, etc.), industrial sites, waste treatment and disposal areas, and in the urban environment (downtown San Francisco).[56] Ground level concentrations at the Geysers, an area of geothermal vents and natural sources of mercury, varied from 0.16 ppb to a peak of 22.5 ppb. A summary of the data for various areas is shown in Table 12.

The previous study indicated elevated mercury levels downwind of such sources as incinerators, industrial plants and natural deposits. For example, it had been suggested that mercury from the Geysers steam vent was being blown 20 miles north to Clear Lake and deposited in the water, where elevated mercury levels in fish have been detected. This data is inconclusive, since it has not been possible to trace an industrial plume for mercury for more than 1.5 miles.

The sources which emit mercury to the air are dispersed over a wide geographic area. A high density of certain sources such as power plants, can be found in urban areas. Although generalized models have been developed,

TABLE 12. SUMMARY OF ATMOSPHERIC MERCURY CONCENTRATIONS IN CALIFORNIA[a]

Site	Date[b]	Wind	Mercury Measurements ($\mu g/M^3$) Background	Peak Value	Remarks
Natural Sources					
Abbott Mine	2/12 (PM)	E	0	0.470	Low population density
Clear Lake	2/12 (PM)	E	0	0.150	Resort area, "
	4/2 (PM)	W	0	0.200	" "
The Geysers	2/13 (PM	W	0.200-0.800	28.100	Rural resort area
New Almadon	1/4 (PM)	(Negl.)	0	1.500	Rural
	3/24 (PM)	NW	0.005-0.015	0.449	Rural
Other Sources[c]					
Berkeley	3/22 (AM)	W	0.010	0.800	Light Indust. - resid.
	3/24 (AM)	W	-	0.449	" "
	3/26 (PM)	W	0.010	0.154	" "
	3/30 (PM)	W	0	1.050	
Oakland/Emeryville	3/30 (PM)	NW	0	0.196	Light industrial
	4/5 (PM)	W	0	0.688	" "
	4/6 (PM)	W	0	0.110	" "
Pittsburg	2/11 (PM)	N	0.050	0.770	Industrial area
	2/12 (AM)	NW	0	1.000	" "
	2/25 (AM)	N	0.006	0.006	On boat
	3/22 (PM)	WNW	0.005	0.010	Residential
	4/1 (AM-PM)	N	0	4.141	Indust. - Residential
San Francisco	3/18 (PM)	-	0	0.278	Commercial area
	3/19 (PM)	-	0	0.152	" "
	1/19-1/26 (AM-PM)	-	0	0.100	Financial District
	4/7-8 (AM-PM)	-	0	0.035	" "
Richmond	3/29 (AM)	NW	0	1.400	Residential (near school)
	3/29 (PM)	W	0.005	2.000	" "
San Carlos	4/6 (AM)	-	0	0.021	Light Industrial
Recommended EPA Ambient Air Concentration[d]				1.0	

a Reference 56
b All locations were sampled in 1971.
c Sources include sewage treatment plant outfalls, waste disposal areas, industrial sites, incinerators, and urban areas.
d Reference 5

the specific dispersion characteristics of mercury in a plume is unknown. This report indicates that at least part of the mercury in the air is transported to the land and water.

The relative effect of mercury emissions from power plants can be assessed through a scenario or an actual study of an isolated power plant.

A scenario was constructed to determine the atmospheric burden of mercury emissions, and assess the effects, under improbable and excessive conditions. The New York City area of about 400 square miles was selected, with a population density of approximately 25,000 persons per square mile. This area accounted for about 34×10^9 Kwh, or 2.4 percent of the total net kilowatt hours generated in the United States in 1974. The electricity was generated at 9 power plants in New York City and 6 in the adjacent area of New Jersey. The following assumptions were made:

- All the mercury from the combustion of the actual oil used and 90 percent of the mercury in the coal actually used in these plants was emitted to the air.
- All the mercury emitted remains in the air, with no intermedia transport.
- A 12 km altitude is considered above the 400 sq. mi. area thus defining an atmospheric volume.
- All the mercury emissions from these plants for the entire year remain in this volume of air.
- All the mercury is evenly distributed within this volume of air.
- There is absolute stagnation, that is, no air enters or leaves this volume.

These assumptions were made improbable and excessive to illustrate an extreme as well as an impossible case. The scenario would, of course, not occur because the emissions would be distributed throughout the year, meteorological conditions would disperse the mercury, and intermedia transfers would remove mercury from the air.

The mercury burden to this atmospheric volume as a result of these power plant emissions under the assumed conditions, is 0.65 g/m^3 or a concentration of 0.52 ppb (wt/wt). When compared with the EPA ambient guideline concentration of 1.0 g/m^3, there remained a safety factor of 1.5, if the minimum ambient background concentration (0.001 g/m^3) was present. With an assumed high background concentration of 20.0 ppb (25 g/m^3) the guideline value is exceeded with a calculated value of 25.65 g/m^3. When compared to the NIOSH recommended workplace exposure of 0.05mg/m^3 for 8 hours, there was a safety factor of 77, when the minimum ambient concentration of 0.001 g/m^3 is considered. Assuming the high background concentration (25 g/m^3) there still remained a safety factor of 1.9.

A calculation was also made to determine the effects of the type of fossil fuel used in generating this same power. Oil yields about three times the mercury that would be emitted by the combustion of coal in generating 1 net KWh. This calculation was based on average mercury content of the fuels and accepted fuel conversion rates.[19] The results show that there would have been a 65 percent reduction in the ambient air concentration, to 0.22 g/m^3, if coal was used in place of oil.

There have been studies to determine the elemental analysis of fuels, fly ash, slag, and flue gas, the emission factors for some pollutants, as well as the mass balance for an operating power plant.[17,21,22,25,29,32,46,57-63] The mercury emissions from power plants, in terms of emission rates and resulting ambient air concentration, has been calculated for the Four Corners and San Juan power plants.[29]

The Four Corners power plant in New Mexico was estimated to require an emission rate 43 times the average daily emission of the power plants in the previous scenario in order to exceed the EPA guideline ambient air concentration of 1.0 g/m^3 (cf Section 6).[29] Based upon the emission at Four Corners, the ambient mercury concentration (24 hour average) was calculated by the EPA to be 0.0365 g/m^3 or less than 4 percent of the EPA ambient guidelines. This was based on a proportionality technique using a diffusion model and a rollback calculation.[29,64]

Projecting this same calculation to the New York City scenario, and assuming all the New York City area plants to be a single point source, the maximum emission to preclude violation of the 1.0 g/m^3 ambient concentration would be 330 kg Hg/day. This is almost 15 times more than these plants emitted in total in 1974. Alternatively, the estimated monthly average ambient air concentration of mercury resulting from the actual estimated mercury emission, is 6.7×10^{-4} gHg/m^3. This provides a safety factor of about 1500.

Water

Many of the waterways in the United States have been the subject of studies and surveys concerning the mercury content of water and sediments. For the purpose of this report we considered four types: lakes, rivers, estuaries, and oceans.

Based on an examination and compilation of data from a number of studies and surveys, the following ranges represent uncontaminated ambient mercury levels in the water and sediments:

Average dissolved Hg content of fresh water bodies (lakes, rivers, streams)	0.01-0.1ppb
Average dissolved Hg content of oceans	0.03-0.3ppb
Average Hg content of suspended sediments	0.1-1.0ppb
Average Hg content of bottom sediments	10-100ppb

The studies used in compiling the ambient concentration ranges were selected as representing a wide geographical area, a wide range of salinities and water body types, and data on mercury in the dissolved, suspended, and settled state. These data are presented in Table 13 grouped according to the water body type. Table 14 presents ambient concentrations of dissolved and suspended mercury in water from USGS of sampling station data within regions.[84] These regions were those used in Section 6 (Tables 5,7,etc.) to define the distribution of power plants. Few studies were comprehensive in measuring both mercury dissolved in the water and present in suspended, and bottom sediments. Similarly, the studies as a whole, while covering a wide geographical area, were not sufficiently comprehensive in the types or locations of waterways to provide a more representative basis for determining background and contamination levels of mercury.

The data showed the concentration of mercury in the fresh water bodies tabulated to be well within the EPA drinking water standard of 2 g/l. However, the various fresh water bodies may have all exceeded the EPA standard for freshwater aquatic life and wildlife of 0.05 g/l. This is difficult to state with certainty as the methods of analysis used varied and in many instances were unable to detect such low concentrations. Variations in observed mercury concentrations in water and sediments may have been a result of either long-term accumulations or source inputs.

An example of increased mercury levels in a body of water, with no apparent source inputs, may be demonstrated by a study of Lake Powell.[65] Lake Powell is a reservoir in New Mexico, fed by the Colorado River, located approximately 4 miles from the Navajo power plant at Page, Arizona. Although the Lake was far removed from man-made sources of mercury prior to the Navajo plant going on-line, accumulation of mercury in sediments, and bioamplification in marine life was observed. Mercury concentrations in game fish had been found to exceed the current HEW-FDA "action level" of 0.500 ppm.[14]

With the scheduled start-up of the Navajo plant, the effects of this potential mercury source on Lake Powell were estimated.[65] It was concluded that the mercury emissions, resulting from the consumption of an estimated 5.9 million tons of coal per year, would enter the lake drainage in the amount of 8 percent of the present total accumulation in the lake. This was based, however, on an unsubstantiated assumption that 40% of the mercury emissions from the power plant would enter the lake drainage.

Variation in the mercury concentrations of water, suspended particulate, and bottom sediments occur as a result of the transport of mercury within the aquatic environment. The concentration of mercury associated with sediments (0.1-1.0 ppb) was found to be higher than that in the water (dissolved mercury) (0.01 -0.1ppb). However, between 55 percent and 86 percent of the total amount of mercury transported was believed to be in solution.[68,83] This would be due to the large volume of flowing water as opposed to the much smaller amount of sediments which is suspended and carried with the water.

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved	SUSP.	Hg, Sed (ppb)	COMMENTS
LAKE POWELL[65]	0.01		49	WATER SAMPLE, PRESUMABLY DISSOLVED
COLORADO R.[65]	<0.1			WATER SAMPLE, PRESUMABLY DISSOLVED
FORBIDDEN CANYON[65]	26			PROCESSED SEWAGE RELEASED, PRESUMABLY DISSOLVED
RIVERS IN ITALY* AND GERMANY[51]	.01-.05			
RHINE RIVER[66]	0.6		ORIGINAL MUD 23,000 EROSION MUD 9,000 FLOOD PLAINS 3000-13000	16 μM FRACTION
EMS[66]			3000	
NORMAL STREAMS, RIVERS AND LAKES[67]	0.01-0.1			
NORMAL GND WATER[67]	.01-0.1			
WALKER BRANCH[68] EAST FORK	30	8100-16500		
WEST FORK[68]	30	11700-17700		
RIVERS OF EUROPEAN USSR[69]	0.4-2.8			
SAALE RIVER GERMANY[69]	0.035-0.145			
RIVER SEINE[69]	0.05-1			
UNCONTAMINATED RIVERS (ITALY)[69]	0.01-0.05			
RIVERS NEAR Hg DEPOSITS (ITALY)[69]	136			

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved		SUSP.	Hg, Sed (ppb)	COMMENTS
FLAMBEAU FLOWAGE, WIS.[70]				110	Ug/g (ppm) ORIGINAL NUMBERS, DRY SED.
OUTLET OT LAKE MICHIGAN[70]				6	
PINE CREEK[70]				16	
BLACK RIVER[70]				5	
WEST BASIN[70]				6	
MARINAS[70]				8	
EAST BASIN[70]				9	
SHIPPING CHANNEL[70]				14	
	DEPTH				
GRAND RIVER 1 mi. UPSTREAM MOUTH[70]	0	.045	.170		
	10	.030	.170		
	15	.025	.170		
MOUTH[69]	0	.035	.195		
	15	.035	.315		
	25	.035	.095		
LAKE, 1 mi. W. OF MOUTH[70]	0	.030	.195		
	30	.065	.120		
	60	.030	.060		
LAKE, 2 mi. W. OF MOUTH[70]	0	.040	.100		
	40	.065	.120		
	80	.030	.060		
LAKE, 7 mi. W. OF MOUTH[70]	0	.030	.090		
	60	.025	.080		
	120	.025	.080		
	195	.015	.045		
	240	.040	.120		
LAKE, 5 mi. NW OF MOUTH[70]	0	.045	.100		
	45	.030	.070		
	90	.025	.045		
	155	.025	.055		
KLEIN LAKE[70]				50	

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved	SUSP.	Hg, Sed (ppb)	COMMENTS
ST. CLAIR RIVER[71]			25,000-130,000	
DETROIT RIVER[71]			6,500	
OTTAWA RIVER[72]				SAMPLINGS IN 1971 AND 1973 IN OTTAWA RIVER AT SAME POINTS CLOSE TO PULP MILL EFFLUENT
1971				
1			1990	
2			250	
3			90	
1973				
1			600	
2			62	
3			16	
STREAMS NEAR HUNTSVILLE, ALA.[73]	0.5 (Avg)			
LAKE MICHIGAN[74]			350-1900	<200μ
RIVER & gnd WATER[75]	0.05			
RAIN WATER[75]	0.15			
LaHAVE R NOVA SCOTIA[75]	0.04-0.10			
SOUTHERN LAKE MICHIGAN[76]			1-5cm 20-360 ppb 5cm 20-880 ppb	
ASHTABULA R.[77]			3-860	
ASHTABULA HARBOR[77]			1-3	
LAKE ERIE[77]			2-120	
FIELDS BROOK[77]			70-580	

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved	SUSP.	Hg, Sed (ppb)	COMMENTS
CUYAHOGA RIVER[77]			1-290	
CLEVELAND HARBOR[77]			10-63	
GRAND RIVER[77]			69-730	
FAIRPORT HARBOR[77]			4-123	
MAUMEE RIVER[77]			1-87	
MAUMEE BAY[77]			3-86	
SANDUSKY BAY[77]			3-180	
LeHAVE R. AND ESTUARY[78]	.036 - 0.380	3590 - 34400	90- 1060	
RED CEDAR R. MICH.[79]			40-400	
LAKE ERIE[80]			SURFACE - 500-4000 DEEPER - 40-90	
RIVER AND GROUND WATER[81]	0.05			
RAIN WATER[81]	0.15			
DELAWARE STREAMS[81]	0.5			
DELAWARE RAINWATER[81]	0.4			
DELAWARE RIVER[81]	<0.1			

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved	SUSP.	Hg, Sed (ppb)	COMMENTS
JAMES RIVER[82]			910	REPRESENTS THE AVERAGE OF 23 SAMPLING POINTS BETWEEN 5-83 MILES
YORK[82]			1320	REPRESENTS THE AVERAGE OF 7 SAMPLING POINTS BETWEEN 5-35 MILES
RAPPAHANNOCK[82]			950	REPRESENTS THE AVERAGE OF 9 SAMPLING POINTS BETWEEN 5-45 MILES
PEE DEE[83]	0.06	500		
BLACK[83]	0.06	600		
SANTO[83]	0.05	200		
COOPER[83]	0.04	1000		
SAVANNAH[83]	0.07	700	70	MARSH CORES - DRY WEIGHT BASIS
OGEECHEE[83]	0.07	600		
ALTAMAHA[83]	0.05	700		
SATILLA[83]	0.07	400		
ST. JOHNS[83]	0.05	600		
RIVER THAMES[69]	0.045 - 2.85			
MINAMATA BAY[69]	1.6 - 3.6			
SAN FRANCISCO BAY[71]			6900	
MINAMATA BAY[75]	1-10			

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved	SUSP.	Hg, Sed (ppb)	COMMENTS
TIDAL THAMES R.[75]		0.045-2.85(T)		
SAN FRANCISCO BAY[75]		20-2000 Avg. 300		
DELAWARE BAY[81]	1-5 (T)		1-4	
SAN FRANCISCO BAY[81]			300	
NEW HAVEN HARBOR CONN.[81]			780	
LeHAVE R. & ESTURARY[81]			340	
DELAWARE BAY SHELL-FISH BANKS[81]			730	
MURDERKILL R. DELA.[81]			240	
ST. JONE R., DELA.[81]			630	
MINAMATA BAY[81]	1.6 - 3.6			
LeHAVE R. & ESTUARY[81]	0.036 - 0.380(T)			
DELAWARE BAY[81]	0.28(T)			
DELAWARE BASIN R.[81]	0.33(T)			
OCEAN[51]	0.03 - 0.27			

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved	SUSP.	Hg, Sed (ppb)	COMMENTS
NORTH SEA[66]	0.1			
SEA WATER	<0.1			
OCEANS AND SEAS[67]	0.005 - 5.0			
NORTH SEA[69]	0.03			
LAMAPO DEEP PACIFIC OCEAN[69]	0.08 - 0.15			
3000m DEPTH[69] (PACIFIC OCEAN)	0.15 - 0.27			
SEA WATER[75]	0.1			
OCEANS[75]	0.03			
DEEP SEA conc.[75]	0.27			
NE ATLANTIC[75]	0.013 - 0.018			
EASTERN PACIFIC[75]	0.022 - 0.173			
ENGLISH CHANNEL NEARBY RIVERS[75]	0.02 0.01			
SEA WATER[81]	0.1			
SOUTHERN CALIF. COAST[81]			340	

TABLE 13. COMPILATION OF Hg VALUES FOR DISSOLVED, SUSPENDED, & BOTTOM SEDIMENTS

SOURCE	Hg, H_2O (ppb) dissolved	SUSP.	Hg, Sed (ppb)	COMMENTS
NW PACIFIC[81]	0.06 - 0.27			
ENGLISH CHANNEL[81]	0.014 - 0.21(T)			
NE ATLANTIC[81]	<0.03 - 0.020(T)			
ATLANTIC OCEAN[81]	0.10(T)			

TABLE 14. SUMMARY OF MERCURY CONTENT IN FRESH WATER BODIES ON A REGIONAL BASIS[a,b]

Region	Hg, dissolved ppb	Hg, suspended ppb
New England		
Connecticut (26)	0.5	0.5
Maine (7)	0.5	0.51
Massachusetts (14)	0.5	0.5
New Hampshire (4)	0.5	0.55
Rhode Island (4)	0.5	0.5
Vermont (3)	0.5	0.5
Middle Atlantic		
New Jersey (18)	-	0.5
New York (34)	0.5	0.52
Pennsylvania (43)	-	0.5
East North Central		
Illinois (19)	0.5	0.66
Indiana (21)	0.5	0.54
Michigan (19)	0.18	0.54
Ohio (24)	0.66	0.86
Wisconsin (16)	0.53	0.54
West North Central		
Iowa (11)	-	0.73
Kansas (12)	-	1.73
Minnesota (10)	-	0.51
Missouri (13)	1.35	1.16
Nebraska (10)	0.5	0.59
North Dakota (7)	-	0.79
South Dakota (7)	-	0.53
South Atlantic		
Delaware (4)	-	0.5
Washington, D.C. (1)	-	0.5
Florida (17)	-	0.83
South Atlantic		
Georgia (17)	-	0.5
Maryland (13)	-	0.5
North Carolina (21)	-	0.5
South Carolina (16)	-	0.5
Virginia (11)	-	0.5
West Virginia (12)	-	0.5
East South Central		
Alabama (18)	0.1	0.5
Kentucky (8)	0.4	0.66
Mississippi (10)	0.49	0.99
Tennessee (12)	0.5	0.5
West South Central		
Arkansas (13)	0.17	0.53
Louisiana (13)	0.5	0.55
Oklahoma (12)	-	0.63
Texas (30)	-	0.55
Mountain		
Arizona (11)	-	0.66
Colorado (19)	-	0.51
Montana (8)	-	0.5
Nevada (8)	-	0.73
New Mexico (15)	-	0.5
Utah (11)	-	0.56
Wyoming (9)	-	0.5
Idaho (8)	-	1.68
Pacific		
California (32)	-	1.31
Washington (14)	-	0.5
Alaska (9)	-	0.57
Hawaii (8)	-	0.81

[a] Reference 84

[b] These data represent the average of several sampling sites within each state. The numbers in parenthesis after the states indicate the total number of samples.

The surface area of the suspended material is an important factor in transporting mercury adsorbed on sediments. Even though higher salinities cause floculation and ultimately the deposition of sediment, it was found that there may be an increase in the mercury concentration towards the mouth of an estuary because the fine grained particulate which adsorb greater amounts of mercury were still in suspension.[79]

Mercury in solution will ultimately be carried to the oceans as would up to an estimated 20 percent of the mercury carried on particulates. The r nainder, carried on particulate, would be deposited in coastal areas.[83] The residence time of mercury in a Georgian estuarine environment, as estimated by Windom, was given as 17 months. It was also estimated that the average half-life of mercury in sediments was 0.78 years.[72] The half-life denotes the period of time until the concentration is half that of the original.

It was found that mercury concentration in the coastal environment exhibited seasonal variation.[83] These variations ranged from 0.005 ppb to 0.3 ppb. The EPA standard for marine waters is 0.1 ppb. These variations could not be explained by variations in estuarine concentration. However, they appeared to be related to offshore winds, whose concentration was found to correlate with the concentration in the water column. This would imply the effect of atmospheric input. While this would be related to mercury emissions to the air an estimate of the effect of mercury emitted from power plants cannot be shown.

The relative effect of mercury emissions from power plants on the aquatic environment can be assessed through a scenario or by an actual study of an isolated power plant.

The scenario constructed was the same as previously described in the discussion on the ambient air concentrations, as an improbable and excessive situation. The following assumptions were made in assessing the effects of power plant emissions on ambient water concentrations:

- All the mercury from the combustion of the actual oil used and 90 percent of the mercury in the actual coal used in the 15 power plants was emitted to the air.
- All of the mercury in the air is deposited in a river as a result of rain, falling at a rate of 45 inches per year. All the rain enters the river.
- A river, with an average flow of 18,000 cubic feet per second, is the receptor. This would be a reasonable composite of 3 rivers in the New York City area.
- All the mercury emissions for the entire year are deposited in the river within a 20 mile length, with no further transport.

- The volume of river water passing the 20 mile length and the volume of rain water for one year's time are the dilution factors.

These improbable assumptions were chosen to illustrate an extreme case. A mercury plume is not expected to always touch down adjacent to the source, nor to completely transport from the air to one or more media.

Under the conditions specified, the total power plant emissions dissolved in the specified river volume results in an ambient water concentration of 0.47 ppb. When compared with the drinking water standard there is a safety factor of 4.25. However, the resulting concentration exceeds the freshwater standard by a factor of 9.4. These conditions could, of course, never occur since the entire plume would not be dissolved in the adjacent water as a result of dispersion of the plume in the atmosphere. The effects would therefore, be reduced.

Deposition rates of mercury from the atmosphere are not known. A scenario study of the effects of mercury emissions from a 1000 MW_e power plant estimated, depositional rates at various distances from the source.[46] Assuming a depositional rate of 2.7 percent of the plume for our previous scenario, the river water concentration would be 0.013 ppb. Compared with EPA drinking water and freshwater standards this condition maintains safety factors of 154 and 3.8 respectively.

The effects of mercury emissions from a single power plant on ambient concentrations were investigated.[85] The study involved a 1200 MW_e power plant situated on a lake, whose water was used for cooling purposes, and surrounded by a watershed. Lake sediment samples showed mean concentrations of 0.049 ppm in the 6 years since the plant went into operation as compared to 0.037 ppm prior to operation. A reduction in concentrations for several years corresponded with the discontinuation of the practice of reinjecting fly ash into the furnace. It was believed that this practice overloaded the electrostatic precipitators which resulted in the emission of large quantities of particulate matter into the air. Mercury concentrations in fish in the lake never reached the U.S. Food and Drug tolerance limit of 0.5 ppm for fish. A conclusion drawn by the authors of this study was that mercury did not appear to be a serious pollutant in the lake.

Soil

To date there has been only one comprehensive study to determine mercury concentrations in soils of the United States.[86] The results of this study are presented in Table 15.

TABLE 15 - CONCENTRATIONS OF MERCURY IN SOILS OF THE CONTIGUOUS UNITED STATES (ppb)[a]

AREA	NO. OF SAMPLES	RANGE	GEOMETRIC MEAN	GEOMETRIC DEVIATION	ARITHMETIC MEAN
Entire U.S.	912	10-4,600	71	2.6	112
Western U.S. (West of 97th Meridian)	492	10-4,600	55	2.46	83
Eastern U.S. (East of 97th Meridian)	420	10-3,400	96	2.53	147

[a]Reference 86

The soils evaluated in this study were sampled at a depth of eight inches in an effort to eliminate any effect of surficial contamination. Soils from the Eastern U.S. showed a higher concentration of mercury than did those west of the 97th Meridian. While this result may not have been expected, since all mercury deposits in the U.S. are located in the west, the higher concentration in the eastern U.S. may have reflected a higher mercury content in the underlying rock with subsequent migration towards the surface. Many of the highest single concentrations detected were, however, from samples in the western U.S.

There have been several attempts at correlating mercury concentrations in soils with point sources.[35,70,85,87-91] Results of the analyses of soils from various land use areas for metals showed a tendency toward higher concentrations in other than residential use areas, which may have indicated a contribution from industrial operations.[70] A data summary is shown in Table 16.

The contribution of emissions from two of the largest sources of mercury to land, copper smelting and chlor-alkali manufacturing, have been studied.[87,90] The soils around a copper smelter, in operation for 84 years, were found to have mercury concentrations ten (10) times the background levels within 1.6km (1 mile) of the plant.[87] No differences were detected beyond 6.4km (4 miles). Similar results were found in the snow around a chlor-alkali plant.[90] The highest concentrations of mercury were found within 500 meters of the plant. Approximately 3.6 percent of the mercury emissions were found in the area from 0.5 to 5 kilometers. Mercury emissions from this plant were from a 10-15 meter high stack at a temperature of between 0° and 10°C. The results of these two studies indicated the local increase in ambient soil concentrations can occur. These source induced increases may have been a result of short term favorable deposition conditions and long term accumulation. These studies would not apply to power plants because of the much greater stack heights as well as elevated temperatures of the stack gas representative of power plants.

TABLE 16. METAL CONCENTRATION RELATED TO LAND USE PATTERNS[a]

		Ag	Ca	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Zn
RESIDENTIAL	median	0.	1,000	0.4	2.	1.6	7.5	2,000	0.07	4.	15.	17.
N = 70	mean	0.13	2,300	0.41	2.3	3.2	8.0	2,200	0.10	5.4	17.9	21.1
	std dev	0.19	2,600	0.44	1.5	3.3	4.5	1,100	0.10	4.1	12.6	12.5
AGRICULTURAL	median	0.	800	0.4	2.5	3.9	5.6	2,200	0.09	6.	11.	17.
N = 91	mean	0.19	1,400	0.57	2.7	4.6	8.8	2,600	0.11	5.6	15.4	22.1
	std dev	0.25	1,900	0.52	1.5	3.6	6.0	1,600	0.09	4.4	14.9	12.9
INDUSTRIAL	median	0.4	1,900	0.7	2.	6.0	11.2	3,200	0.11	7.	22.	32.
N = 86	mean	0.37	3,200	0.66	2.8	8.5	16.3	3,100	0.14	8.3	47.7	56.6
	std dev	0.33	3,000	0.54	1.8	9.0	14.3	1,400	0.10	5.2	59.6	63.1
AIRPORT	median	0.4	3,700	0.7	8.	22.	9.4	7,000	0.17	11.	14.	36.
N = 7	mean	0.29	4,100	0.77	7.9	17.6	10.4	6,200	0.33	12.3	17.9	36.6
	std dev	0.30	3,800	0.56	2.7	8.9	2.1	1,600	0.18	5.9	8.4	15.0
INDUSTRIAL/RESIDENTIAL		2.85	1.39	1.61	1.22	2.66	2.04	1.41	1.40	1.54	2.62	2.68
AIRPORT/RESIDENTIAL		2.24	1.78	1.88	3.43	5.50	1.30	2.82	3.30	2.28	1.00	1.74

[a]Reference 70

The effects of power plant emissions on ambient soil concentration are of concern because of possible effects on plants, animals, food, and humans. Attempts have been made to correlate their emissions with ambient soil concentrations.[35,46,85,88,89,91]

Two of the studies resulted in no detection of increased soil or plant concentrations from mercury emissions within 32 and 50 km respectively.[35,88] Another study indicated less than 2 percent of the mercury emitted was deposited within 8 km, the remainder probably being widely dispersed.[89]

Mercury contamination of the ground around a chemical plant in Northern Virginia was studied in an effort to determine the source.[91] The local health agency collected samples within Alexandria, Virginia and along the shore of the Potomac around Oronoco Bay. The concentration in the soil samples ranged from <0.18 ppm to 17.6 ppm. They considered the normal soil background to be 0.5ppm. The conclusion of the local health agency was that a local coal-burning power plant was the source. Their calculations, based upon 22 samples, indicated that the total amount of the mercury emitted by the plant was deposited within a 1.6 km (one mile) radius and remained within a 7 cm depth. Although the power plant had no emission controls for most of its 25 year operating history, the small number of samples analyzed and the calculation of deposition would leave their conclusion open to question. The power plant was most probably only one of several sources contributing to elevated soil concentrations over the years.

A study of an isolated 1200MWe power plant, located in the center of a watershed in Illinois, concluded that there was a statistically significant increase of mercury concentration in the soil northeast of the plant, the direction of the prevailing wind.[85] The background level was assumed to be 0.015 ppm, found southwest of the plant, as compared to the higher levels of 0.02? ppm downwind. These elevated values are less than 1/3 of the geometric mean mercury concentration for the United States. It was also concluded that between 26 percent and 70 percent of the total mercury emissions of the plant, since being put into operation, was incorporated into the soil within a 19.3 km radius of the plant. This conclusion, however, was based upon assumptions and extrapolation of measured surface soil concentrations to plow depth (17 cm.). The soil data was presented without any distinction being made as to the type of soil surrounding the plant from which the samples were taken. There was a difference in the soil between the northern and southern sides of the plant. These soils may interact with mercury differently thus affecting the mercury levels found, its form(s), and residence time. The implication was that much of the mercury emitted was deposited within 20 km and remained immobile, neither occurance of which has ever been proven.

A model was constructed to describe the transport and deposition of mercury from the atmosphere, and to determine the increase in the mercury concentration of soil within a 25 km radius due to a 1000 MWe power plant and an incinerator as point sources.[46] The conclusions were, that even

though incinerator deposition is more local than power plants, only a small amount of the mercury emitted is deposited locally, with at least four-fifths of the mercury remaining airborne to be further dispersed.

Using the scenario previously constructed, of the 15 power plants in the New York City area, the following assumptions were made to create an improbable and excessive case:

- All the mercury from the combustion of the actual oil used and 90 percent of the mercury in the actual coal used in the 15 power plants was emitted to the air.
- All of the mercury emitted to the air in one year is deposited uniformly over the 400 square miles.
- The mercury is deposited within the first 2 cm of soil.
- The entire mercury deposition remains in this volume of soil.

This improbable scenario resulted in a soil concentration of 145 ppb due to the emissions, which is two times the geometric mean concentrations for United States soils. If 20 percent of the mercury emitted is assumed to be deposited within this same area, the resulting concentration is 29 ppb, or 40 percent of the United States geometric mean concentration. Neither case could occur since the emissions would be distributed throughout the year, and transport and transformation mechanisms would be present to further lessen the impact.

However, buildup of mercury in the soil could occur over the long term. Additional factors affecting deposition of mercury would be the emissions conditions from the power plant, such as stack height, buoyancy, dispersion, and dilution. From these examples it can be concluded that:

- No definitive studies have been performed which would allow the quantifying of the effects of mercury emissions from power plants on soil.
- Elevated concentrations in the soil have been observed in the vicinity of power plants.[85,91]
- A distance from a plant can be reached beyond which there will be no detectable increase in soil concentration. This is due in part to the limited amount of the mercury emissions being dispersed and distributed over increasingly larger areas. Another factor would be the revolatilization of mercury with subsequent reentry into the atmosphere to be further dispersed.[46,51]

CHEMICAL, PHYSICAL, AND BIOLOGICAL TRANSFORMATIONS

The transport of mercury between environmental media as well as the subsequent concentration, depend in part, on the form in which mercury exists and the transformations which it may undergo. This section examines these transformations with respect to the presence of mercury in the environment.

Air

Mercury enters the air as metallic vapor (Hg^o), organic mercury compounds or other compounds.[92,93] Metallic mercury is transported into the air by vaporization, because of its high vapor pressure at normal temperatures. The vapor pressure at normal temperatures is 1.2×10^{-3} mm Hg at 20°C, and increases with the temperature. The saturation concentration of mercury in the air at room temperature is 10-15 mg Hg/m^3. Vaporization is evidenced by higher ambient air concentrations over areas with mercury deposits than over non-mineralized areas.

Ionized forms of mercury can be transformed into volatile forms by three processes. These are chemical reduction to the elemental form, reduction through the action of organisms, and biotransformation into volatile organomercury compounds such as short chain alkyl mercurials. Chemical reduction, while carried out in laboratory experiments, has not been studied in nature. One laboratory observation was made by Kimura and Miller, in which about 15 percent of added phenyl mercury acetate was converted to metallic mercury vapor in 28 days, while ethyl mercury was only partly converted and methyl mercury not at all.[92] The latter two, however, volatilized in their original forms.

The volatilization of mercury induced by bacterial activity, while not studied extensively, has been observed by Barker.[92] His data showed that live Pseudomonas released 4-30 times as much mercury as dead control cells. Biotransformation by animals has been shown by experiments with rats in which labelled mercury ion was found in the exhaled breath of rats which had been injected with radioactive mercury. Natural evapo-transpiration from vegetation has also been observed.[39,51]

The rate of vaporization of mercury and some inorganic mercury compounds has been shown to decrease in the following sequence:[94]

$$Hg^o > Hg_2Cl_2 > HgCl_2 > HgS > HgO$$

Vapor pressure of mercurial fungicide is greater for methyl and ethyl forms than phenyl forms, $0.8\text{-}23 \times 10^{-3}$ mm Hg @ 35°C versus $0.8\text{-}17 \times 10^{-6}$ mm Hg @ 35°C. Methyl mercuric chloride was found to be the most volatile of the methyl, ethyl, and phenyl compounds tested, with a value of 23×10^{-3} mm Hg @ 35°C. The methyl and ethyl forms tested, other than methyl mercuric chloride, have a similar volatility to that of metallic mercury, $1.2 - 3.4 \times 10^{-3}$ mm Hg.[95]

Mercury emissions from power plants may form HgS on cooling. However, the mercury emissions are most probably in the metallic or non-charged state, namely Hg^{o}. The Hg^{o} in the atmosphere may condense or be adsorbed onto particulates. However, nothing is known about the fate and transport of mercury in the atmosphere.

The mercury released by the power plant in the plume may be carried over a wide geographic area to be dispersed to the environment. There are differences of opinion concerning the distance and rate at which Hg° is deposited from the original power plant source.[35,46,85,88,89,91]

These opinions include: all emissions deposited in the immediate vicinity of the plant (within 1 mile); 2-20% deposited within 20 km.; 26-70 percent within 19.3 km; 2 percent within 8 km.; and none detected within the first 32 and 50 km. Present information does not provide answers to the questions of either the deposition rate of mercury nor the distance over which mercury may be transported.

The dispersal and distance traversed by the plume is dependent upon such factors as stack height, plume buoyancy, and meteorological conditions.

Water

The effect of power plant emissions of mercury on man and the environment, depends upon the concentrations of the various resulting forms of mercury and their toxicity. Some forms of mercury have a greater toxicity, such as the organomercurials, (monomethyl and dimethyl mercury), while other forms have a lower relative toxicity. Therefore, total mercury concentrations are not sufficient to assess the mercury hazard.

The objective of this section is to define the transformations of mercury in water and the conditions which lead to these transformations. Figure 3 represents the common pathways in water for the transformation of Hg°. Figure 4 shows the distribution of mercury compounds in the environment.

Physical Transformation--

It is uncertain whether or not there is significant transfer of mercury directly from air to water. The direct intersection of a plume with a body of water may provide for the direct transfer of mercury. The other path, indirect transfer, involves the deposition on the ground followed by runoff. The exact nature of the transport and transformation of mercury is not known.

Chemical Transformation--

The highest concentrations of mercury is found in the sediments as compared with mercury dissolved in water. The relative solubility of the various mercurous and mercuric compounds will determine the partitioning between mercury on particulate and dissolved mercury. The relative solubilities of mercury and some mercury compounds are listed in Table 17.

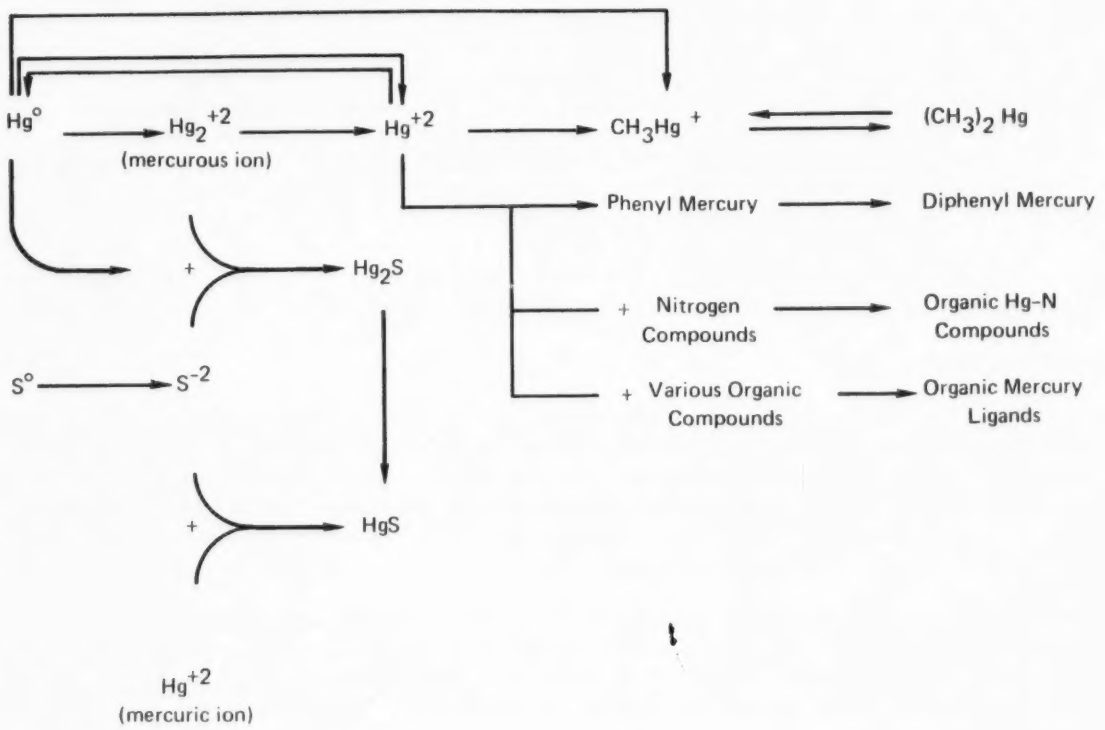


Figure 3. Common pathways of mercury transformation in water.

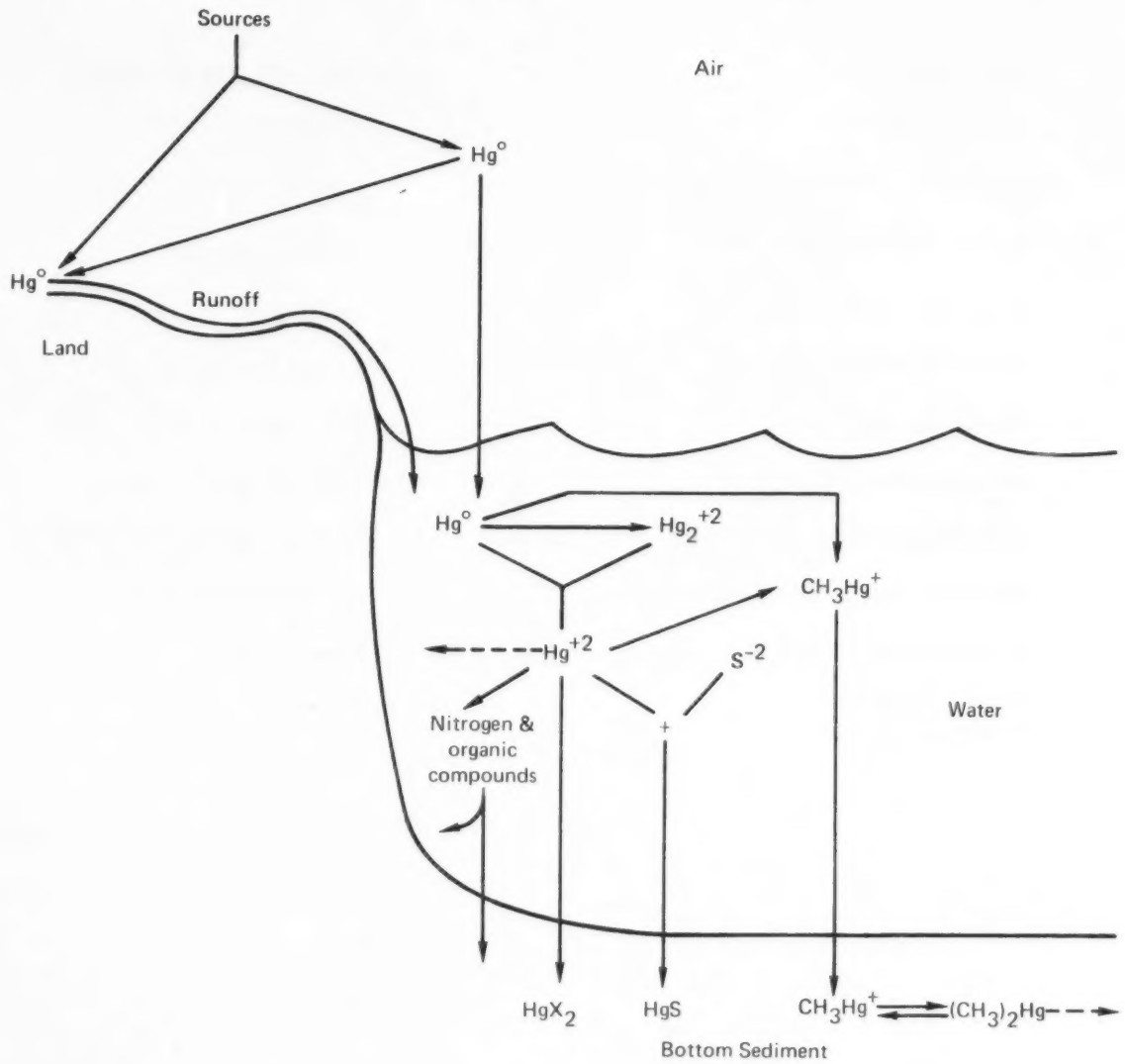


Figure 4. Distribution of mercury compounds in the environment.

TABLE 17

RELATIVE SOLUBILITIES OF MERCURY AND SOME MERCURY COMPOUNDS[a]

Substance	Solubulity (cold water)
Mercury, Hg°	insoluble
Mercurous Chloride, Hg_2Cl_2	2 mg/l @ 25°C
Mercuric Chloride, $HgCl_2$	69 gr/l @ 20°C
Mercurous Oxide, Hg_2O	insoluble
Mercuric Oxide, HgO	53 mg/l @ 25°C
Cinnabar, HgS	0.01 mg/l @ 18°C
Metacinnabar, HgS	insoluble
Dimethylmercury, $Hg(CH_3)_2$	very slightly soluble[b]
Methylmercuric Chloride, CH_3HgCl	no available data
Methylmercuric Iodide, CH_3HgI	insoluble

[a] Reference 96
[b] Reference 97

Solid and liquid forms of mercury are stable and soluble under certain conditions of pH and redox potential in most natural waters. Calculations were made and plotted for species at 25°C and 1 atmosphere of pressure.[98] These are shown in Figures 5 and 6.

Figure 5 shows the fields of stability for various inorganic compounds of mercury where the system is aqueous containing 36 ppm Cl^-, 96 ppm SO_4 = at 25°C and 1 atmosphere pressure as a function of Eh and pH. Both solid and liquid forms of mercury may exist depending upon the conditions. If liquid metallic mercury is formed it may volatilize and escape to the open atmosphere. In well-oxygenated waters where there is a positive Eh and the pH is between 5.5 and 9 (8.3 = average pH of natural waters), liquid metallic mercury and solid HgO would be predominant. Under more acidic conditions solid mercury chlorides would exist. In poorly oxygenated waters where reducing conditions exist solid HgS will be the predominant species.

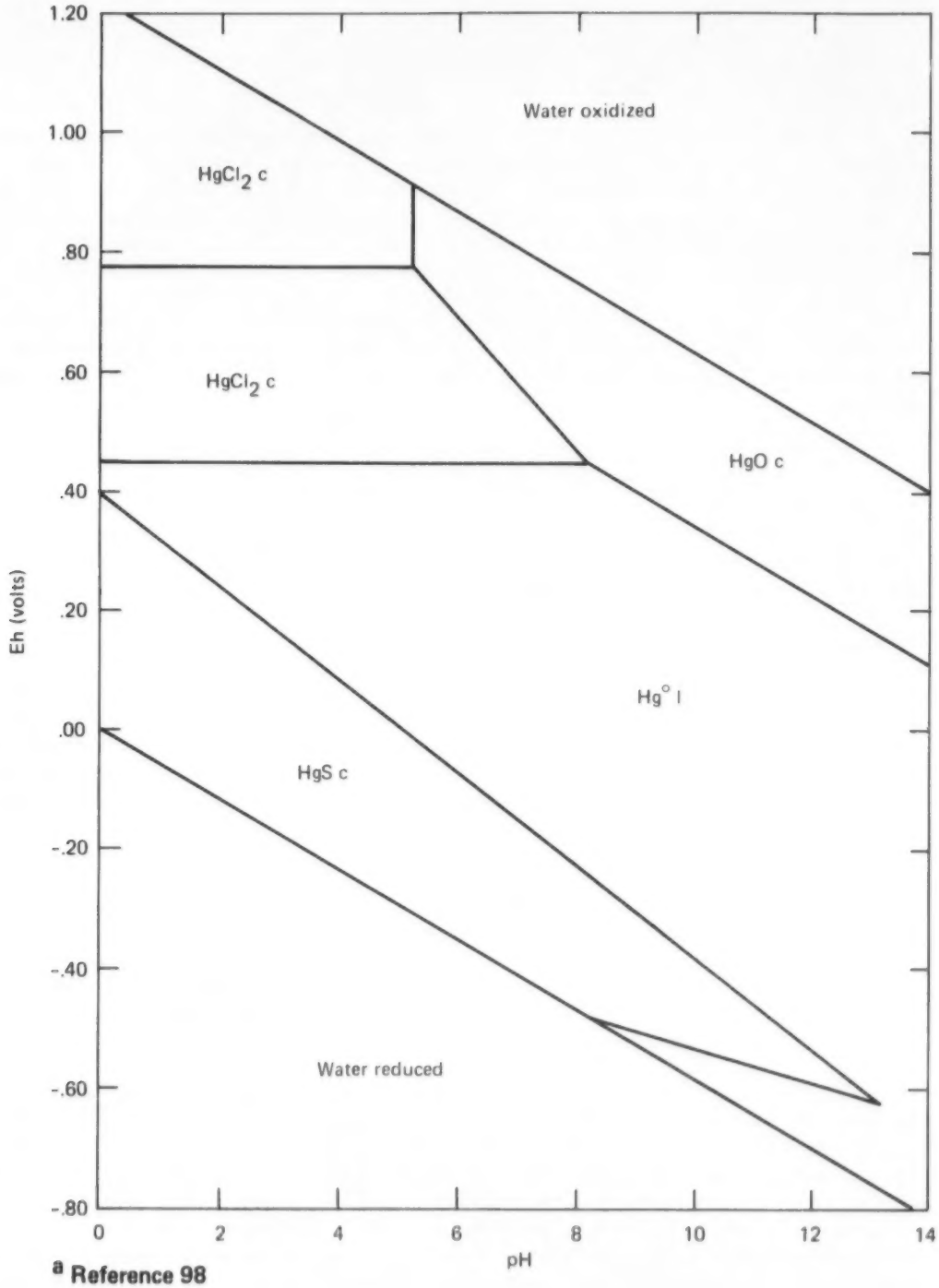
Figure 6 shows the fields of stability for aqueous mercury species under the conditions stated above as a function of Eh and pH. In well oxygenated waters of a positive Eh above 0.3 volts and pH between 5.5 and 9, Hg° (aq), and $Hg(OH)_2^\circ$ (aq), $HgCl_2^\circ$ (aq), and Hg_2^{+2} will be the major species found. At lower Eh values and decreasing pH soluble mercury sulfide species [$Hg(HS)_2^\circ$ (aq) and (HgS_2^{-2}) (aq)] will begin to predominate.[98,99].

Biological Transformation--

Transformation of the various forms of mercury may occur through biological mechanisms. Micro-organisms are the primary source of transformation, although many organisms, including mammals, have biochemical systems capable of methylating a variety of compounds.[100-106] Consideration must therefore be given to the assessment of micro-organisms present in any given body of water.

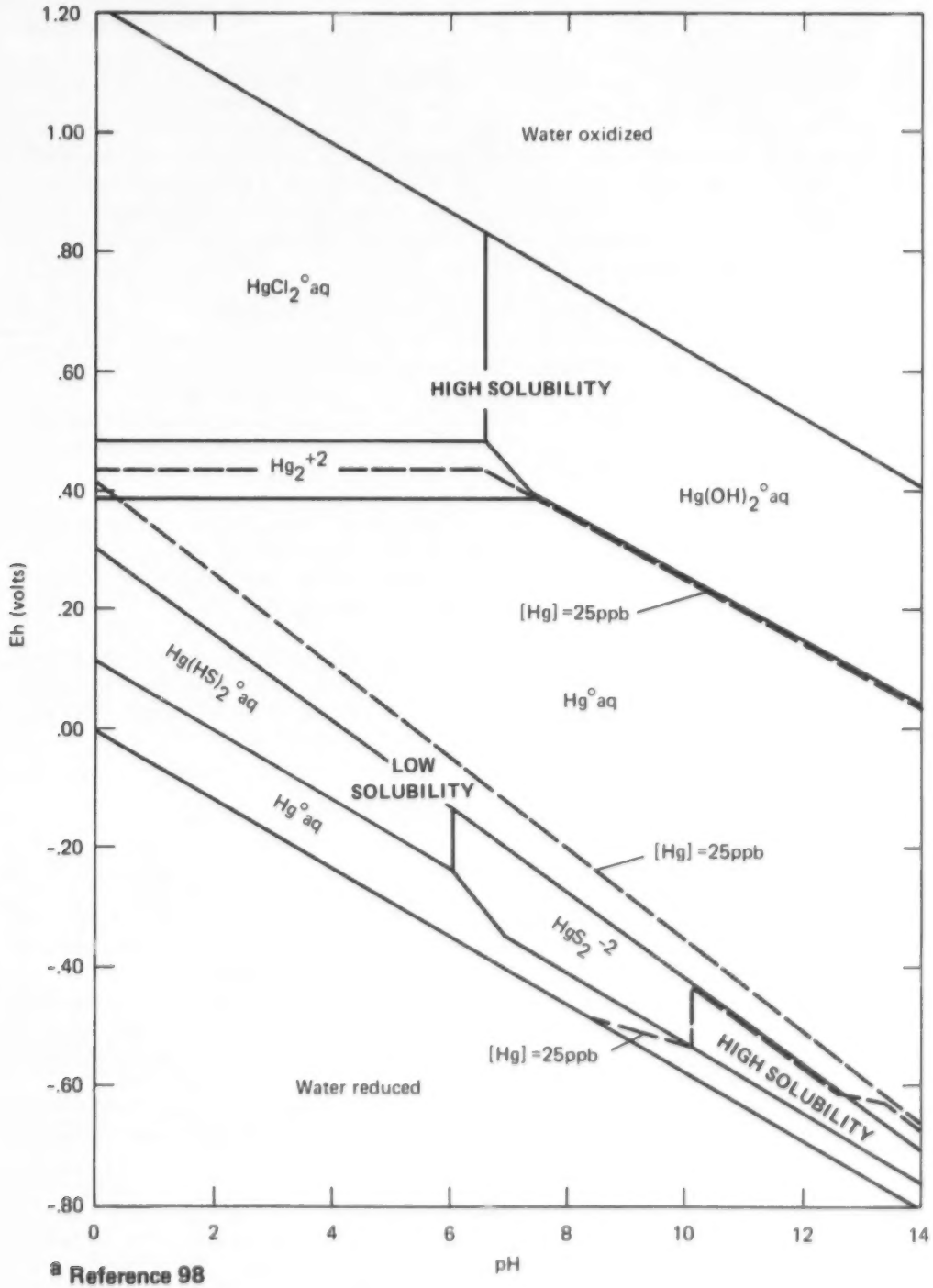
The micro-organisms considered to be methylators are primarily aerobic and anaerobic bacteria. The mechanism and conditions under which they methylate are discussed in the literature.[107-115] An estimate of the annual production rate of methylmercury was 50 g/g of total mercury. Most mercury in the water adsorbs onto living cells or suspended particles, with significant concentrations having been found in the intestines of feeding fish and other organisms.[112,116-118].

Most mercury which enters the aqueous environment becomes methylated, forming the methyl or dimethyl species depending upon conditions. The more volatile dimethyl form is more toxic than the methyl form. The potential hazard depends on toxicity, rate of breakdown, and duration and type of exposure. Concentrations are usually not high enough to cause acute posioning. However, many organisms concentrate mercury in their tissues which can lead to their death or ultimately cause chronic mercury poisoning humans if the organisms are ingested. Chronic poisoning is dependent upon concentration, rate of ingestion, and time.



[a] Reference 98

Figure 5. Phase diagram for solid and liquid mercury species.[a]



[a] Reference 98

Figure 6. Phase diagram for aqueous mercury species.[a]

Soil

Mercury deposits occur in nature in a number of forms, primarily cinnabar, HgS. The presence of mercury in the various ores and rock formations are shown in Table 18. Mercury, in trace quantities, migrates to the general environment from these natural sources. Some of this is probably as HgS. Mercuric sulfide, HgS, is virtually insoluble in water, and also has a very low vapor pressure. Where alkaline reducing conditions exist, along with the sulfide concentrations, the formation of the rather soluble HgS_2^{-2} ion may facilitate mercury transport.

The increased presence of Hg_2Cl_2, with increasing distance from natural deposits, may lead to the conversion to Hg° and $HgCl_2$ near the surface. This is expected to occur near the surface in the presence of water and ultraviolet radiation. Since $HgCl_2$ is soluble it may be expected to pass into solution and be transported as leachate until a change in pH occurs. The stability diagrams for various pH - Eh conditions have been discussed previously in Section 7 and shown in Figures 5 and 6.

Methylation of the divalent mercury ion has also been found to occur in soil systems. The production of methylmercury was found to be affected by soil concentrations of mercury, soil texture, soil water content, soil temperature, and time and to be directly proportional to percent clay content.

A decrease of methylmercury concentrations in soil with time has been observed. The methylmercury production rate in natural soil systems has not yet been quantified, but laboratory studies have indicated that under certain conditions methylmercury production could be a significant part of the cycling process.[119]

A quantification of the effect of each mechanism is not feasible due to the interaction of the various elements, the complexity of the mercury cycle, and the dependence on local conditions. However, some general statement concerning transformations can be made. The degassing rate of a number of non-mineralized and mineralized areas was measured.[120] It was estimated that a natural background degassing level for non-mineralized areas was 0.2 g/m^2/day with higher rates for mineralized areas.[120] It was also concluded in this study that concentrations at the soil/air interface correlated best with mercury concentrations in underlying deposits and not with surface concentrations. A rough correlation between soil concentrations and degassing rate probability exists but due to the number of factors such as temperature, barometric pressure, soil type, etc. a relationship has not as yet been developed. Mercury which is not degassed may become organically bound to the soil and immobilized.

The quantitative relationship of these transformations to mercury emissions from power plants cannot be determined. With definitive information regarding the deposition of mercury from a power plant plume, the transformations and ultimate fate of the mercury could be determined. However, as previously discussed, the initial information is as yet still unknown.

TABLE 18. MERCURY CONTENT OF ORES, ROCKS, AND MINERALS[a]

MINERAL	NORMAL RANGE (ppm) LIMITS	HIGHEST REPORTED CONTENT (%)
tetrahedrite	10. -1,000	17.6 ;21
grey copper ores	5.0 - 500	14.
sphalerite	0.1 - 200	1.
wurtzite	0.1 - 200	0.03
stibnite	0.1 - 150	1.3
realgar	0.2 - 150	2.2
pyrite	0.1 - 100	2.
galena	0.04 - 70	0.02
chalcopyrite	0.1 - 40	-
bornite	0.1 - 30	-
bournonite	0.1 - 25	-
chalcocite	0.1 - 25	-
marcasite	0.1 - 20	0.07
pyrrhotite	0.1 - 5	-
molybdenite	0.1 - 5	-
arsenopyrite	0.1 - 3	-
orpiment	0.1 - 3	-
native gold	1.0 - 100	60.
native silver	1.0 - 100	30.
barite	0.2 - 200	0.5
cerussite	0.1 - 200	0.1
dolomite	0.1 - 50	-
fluorite	0.01 - 50	0.01
calcite	0.01 - 20	0.03
aragonite	0.01 - 20	3.7
siderite	0.01 - 10	0.01
chalcedony and opaline silicas	0.01 - 10	-
quartz	0.01 - 2	-
pyrolusite	1.0 -1,000	2.
hydrated iron oxides	0.10 - 500	0.2
graphite	0.5 - 10	0.01
coal	0.05 - 10	2.
gypsum	0.01 - 4	-

ROCK TYPE	RANGE	MEAN
(a) IGNEOUS		
Ultrabasic (dunite, kimberlite, etc.)	7 - 250	168
Basic intrusives (gabbro, diabase, etc.)	5 - 84	28
Basic extrusives (basalt, etc.)	5 - 40	20
Intermediate intrusives (diorite, etc.)	13 - 64	38
Intermediate extrusives (andesite, etc.)	20 - 200	66
Acidic intrusives (granite, granodiorite, syenite)	7 - 200	62
Acidic extrusives (rhyolite, trachyte, etc.)	2 - 200	62
Alkali-rich rocks (nepheline, syenite, phonolite, etc.)	40 -1400	450
(b) METAMORPHIC		
Quartzites	10 - 100	53
Amphibolites	30 - 90	50
Hornfels	35 - 400	225
Schists	10 -1000	100
Gneisses	25 - 100	50
Marbles, crystalline dolomites	10 - 100	50
(c) SEDIMENTARY		
Recent sediments: stream and river	10 - 700	73
lake	10 - 700	73
ocean and sea	< 10 -2000	100
Sandstones, arkoses, conglomerates	< 10 - 300	55
Shales, argillites, mudstones	5 - 300	67
Carbonaceous shales, bituminous shales	100 -3250	437
Limestones, dolomites	< 10 - 220	40
Evaporites: gypsum, anhydrite	< 10 - 60	25
halite, sylvite, etc.	20 - 200	30
Rock phosphates (composite samples)	--------	120

[a]Reference 47

SECTION 8

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